

THE PROJECTED IMAGE AND THE
INTRODUCTION OF INDIVIDUALITY IN
ITALIAN PAINTING AROUND 1270

SUSAN GRUNDY

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THE PROJECTED IMAGE AND THE INTRODUCTION OF
INDIVIDUALITY IN ITALIAN PAINTING AROUND 1270

by

SUSAN AUDREY GRUNDY

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PROMOTER: DR BMR VAN HAUTE
JOINT PROMOTER: DR C FALCO

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DECLARATION

I declare that THE PROJECTED IMAGE AND THE INTRODUCTION OF INDIVIDUALITY IN ITALIAN PAINTING AROUND 1270 is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

Susan Audrey Grundy

SUMMARY

Before the publication of David Hockney's book *Secret Knowledge: rediscovering the lost techniques of the Old Masters* in 2001, it was commonly believed that the first artist to use an optical aid in painting was the seventeenth-century Dutch painter Johannes Vermeer. Hockney, however, believes that the use of projected images started much earlier, as early as the fifteenth-century, claiming that evidence can be found in the work of the Flemish painter Jan van Eyck. Without rejecting Hockney's pioneering work in this field, I nevertheless make the perhaps bolder claim that Italian artists were using the aid of image projections even before the time of Jan van Eyck, that is, as early as 1270. Although much of the information required to make an earlier claim for the use of optics can be found in Hockney's publication, the key to linking all the information together has been missing. It is my unique contention that this key is a letter that has always been believed to have been European in origin. More commonly referred to as *Roger Bacon's Letter* I show in detail how this letter was, in fact, not written *by* Roger Bacon, but addressed *to* him, and that this letter originated in China. Chinese knowledge about projected images, that is the concept that light-pictures could be received onto appropriate supports, came directly to Europe around 1250. This knowledge was expanded upon by Roger Bacon in his *Opus Majus*, a document which arrived in Italy in 1268 for the special consideration of Pope Clement IV. The medieval Italian painter Cimabue was able to benefit directly from this information about optical systems, when he himself was in Rome in 1272. He immediately began to copy optical projections, which stimulated the creation of a new, more individualistic, mode of representation in Italian painting from this time forward. The notion that projected images greatly contributed towards

the development of naturalism in medieval Italian painting replaces the previously weak supposition that the stimulation was classical or humanist theory, and shows that it was, in fact, far likely something more technical as well.

KEY TERMS

David Hockney; optical aids in painting; image projections; medieval Italian painting; Cimabue; Duccio; Roger Bacon; Roger Bacon's Letter; camera obscura; naturalism in painting.

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PREFACE

In 1974, as a high-school student in Rhodesia, I chose Art as a way of getting out of Latin. The headmaster assured us that it was the last year such a frivolous option would be available to academic students. Although ‘O’ Level Art was a practical subject our teacher gave us weekly lessons in art history. During one of these lectures she showed us slides of Vermeer’s paintings. I cannot truthfully report her exact words, but very dismissively she claimed that Vermeer was not a “real” artist because he had traced using a camera obscura. Moving swiftly along, she clicked over to the next artist on her list. I forget who that was; suffice to say she would have paused more respectfully over someone she considered to be a “freehand” master. I, and no doubt some of my classmates, was left wondering what a camera obscura was and how it worked, but I felt suitably educated to always disdain this Vermeer artist for having used one.

It was not until 2000, during a trip to England, that the use of the camera obscura as an aid to realist painting once more came to my attention. While there I read in the press about David Hockney and his optical theories. I eventually discovered *Secret Knowledge* (2001) on the new-book shelf of the university library. The presentation did not immediately engage me and I found the appendices, with the correspondence and so-called evidence, confusing. However, what did catch my eye was Hockney’s claim that Caravaggio had used a camera obscura. I had chosen a follower of Caravaggio as the focus of an honours degree article so this was of immediate interest to me. I decided that if Caravaggio had

used a camera obscura then so too had Artemisia Gentileschi. It was an epiphany. My exact thought was: that's it, that's how she did it. I decided it was time to do a Master's degree.

I proposed the title *Artemisia Gentileschi's Looking Glass*, my first aim being to deconstruct Artemisia's most famous youthful painting, the Pommersfelden *Susanna and the Elders* (1610).¹ This painting, an incredible triumph of professional virtuosity, had been done when she was just seventeen. It became evident that it was simply not known how she achieved this standard, most especially as she was not only young, but also suffered all the inherent restraints of being a seventeenth-century woman. However, as my dissertation progressed, proving Artemisia had used a camera obscura required an in-depth exploration of the same claim for Caravaggio. Thus my titled lengthened to *Artemisia Gentileschi and Caravaggio's Looking Glass* (Grundy 2004).

Although research into the camera obscura and painting before Vermeer was in its infancy, it turned out that Hockney had not, in fact, had the first word on Caravaggio and lenses, although his voice has been the most public. Under the appendices of *Secret Knowledge* is the extract of an article by Dr Roberta Lapucci. Keen to read the whole of her article about Caravaggio and optics, I duly ordered it from the library. However, the Italian was significantly above my comprehension, so early in 2005 I made an appointment to meet Roberta personally in Florence. We established an immediate friendship and fruitful working relationship, and towards the end of 2005, with the assistance of Sarah Mongelli, we published a full and authorised English translation of her seminal article. Roberta and I

continue to work closely and her enthusiasm for all things Caravaggio is always stimulating.

Having completed my Master's degree in 2004 I eventually registered for a doctoral degree in 2006, with the initial aim to cover the early Hockney starting point of 1420 and to concentrate on Flemish artists. It was by accident that I stumbled on a beginning point (in the tradition of Italian painting at least) that was fully one hundred and fifty years earlier than had even been suspected by Hockney. Looking through a general art book for examples of Byzantine and/or Gothic painting that I could compare in a more rigorous way to Masolino or to van Eyck (than I believed Hockney had) I stumbled across two artworks that, in my opinion, turned the "optical look of 1430" notion on its head. On a double-page spread in *L'arte Italiana: pittura, scultura, architettura dalle origini ad oggi* (2000) the editor, Gloria Fossi, has juxtaposed the Rucellai *Madonna* (1285, plate 13) and *Washing the Feet* from the *Maestà* (1308–1311, plate 28(vi)), both attributed to Duccio di Buoninsegna. The Rucellai *Madonna* is medieval in its formal and idealised presentation, with crouched angels dressed in delicate pastels, and the centralised figures of Mary and baby serene and idealised. By comparison the figures of the apostles in *Washing of the Feet* are much more animated, with varying and individualised physiognomies. Although I could only identify five models (repeated in various numbers and poses), the fact is they *are* models. Here was an artist looking at living bodies and faces, and capturing expression and personality. These are empirically observed, carefully studied, tiny portraits of individuals. Contrary to certain perceived notions that Italian naturalism was

founded solely on relearning from classical sources, I began to wonder if there might have been a more technical stimulus as well. What I subsequently have discovered is that in Italy, between 1270 and the beginning of the fourteenth century, there was an obvious relationship between art and optics, which helped to stimulate Italian painting into new directions.

In the preparation of my doctoral thesis I would like to thank Dr Bernadette Van Haute, my promoter at the University of South Africa. She and I have not always seen eye to eye, but she nevertheless always essentially believed in the thrust of my argument. She has, over the years that I have been working under her guidance, made so many valuable comments that her contribution cannot be considered insignificant. Her assistance has greatly enhanced my approach and methodologies, and steered me away from sometimes contradicting myself. Dr Van Haute was also the supervisor of my Master's dissertation.

My second promoter, Dr Charles Falco of the University of Arizona, has made a number of insightful comments on the text of this thesis, which helped me to tailor the rigors of available scientific methodologies to the presentation of an art historical argument in a way that, I hope, will be found interesting to both art historians and scientists. E-mail exchanges with Dr Falco are always motivating.

I have also forged many informative relationships with scholars in different countries. Among these I would like to thank Dr John Spike of Florence, whose conversations are always inspirational, Dr Michael Gorman in Ireland, who did much early research on Caravaggio and optics, Ramon van der Wekend in the Netherlands, an artist and fellow optical experimenter, Dr Claudio Pernechele in

Padua, whose scientific approach has helped me to refine my own methodologies, Dr Sven Dupré of the University of Ghent, who met with Dr Van Haute and I in October 2006, and whose work on Galileo has informed some of my opinions, and Prof. Nicholas Allen of Port Elizabeth, whose research on the Turin Shroud and the camera obscura certainly gave me courage.

I would especially like to thank David Graves for corresponding with me over a number of years and exchanging many fruitful ideas. As the preparation of this thesis was coming to an end I was able to meet David Graves and David Hockney in Florence, at the Studio Art Centres International *Painted Optics Symposium* (2008). Unquestionably without David Hockney's published research I would not be in this field.

On a final note, I would like to thank the Financial Aid Bureau at the University of South Africa for awarding me financial assistance and making this degree possible.

Notes to this section

¹ Artemisia Gentileschi, *Susanna and the Elders* (1610). Oil on canvas, 170 × 119cm. Signed (on wall behind figure): ARTIMITIA / GENTILESCHI F / 1610. Collection of Graf von Schönborn, Pommersfelden, Bayern. Inventory: 191. (Christiansen & Mann 2001:296–9.)

LIST OF ILLUSTRATIONS

The illustrations are grouped into two sections. The figures in Section 1 consist of illustrations that are not original paintings, that is, they are illustrative drawings or are my own computer-generated graphics. The plates in Section 2 are all images of original paintings that I present more-or-less sequentially in order of the first relevant reference in the text, that is, from chapter two onwards. Exceptionally, I have grouped the whole of Duccio's *Maestà* under one plate (that is, plate 28), using Roman numerals to indicate the various parts and individual aspects of this particularly large artwork.

SECTION 1

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INTRODUCTION

Although art history is concerned primarily with the surface of the painted image, absolute currency is given to the real object as art. It could be said, therefore, that paintings have more than one level of value. The object per se, that is, the canvas, the wooden panel, the icon, the altarpiece or other type of painted support, will have one price. This object will be owned either by a person or an institution. Knowledge of the original painted image, which was previously dispersed beyond the physical boundaries of the resting place of the art object by such means as lithographs, other artists' copies, etchings, and so on, is now generally available through the medium of photography. It could even be argued that without photography the modern discipline of "art history" would not exist in its wider application, as the previously inaccessible painted image is now able to be photographed and rapidly disseminated through digital processing in printed publications and on the Internet. This photographed image of the painted object receives another value to the physical painted object, and we call this copyright. Strictly speaking, while the creator of the artwork is alive, and for seventy years after his or her death, the copyright of the surface image remains with the artist. Practically, the owner of the art object controls the copyright, and what remains most valuable is the actual painted object.

Nevertheless, today the value of the painted object, its reputation, is built up around the dissemination of the photographed image, although any photograph of the object has no value, except as copyright. Some artists use the

process of photography as an artistic medium, but any (artistic) photograph, even by the most established and renowned modern artist, is usually not worth anywhere near what a painting can be worth. One of the problems for photography as an art form is that this art object (that is, the photograph by an artist) is already at a lower level of value than an actual painted object. It must be said, therefore, that as a culture we simply do not value photographs the way we value paintings. Some people might even consider painted objects based primarily on photography to be less valuable. As painting became more perceptual, a trend which could be said to have dominated Western-European painting from around 1270 through to the mid-nineteenth century, it is the painters' skills, their seemingly superior hand-eye coordination, their perceptiveness, and their years of dedicated training, which we have been taught to appreciate. So how should we feel about finding out that apparently many artists could have been tracing, that is, they were doing essentially what a camera does and capturing the essence of an already-existing flat image?

The projection of images is a natural phenomenon, whereby the image of any object placed outside in bright enough sunlight can be captured through a small hole of about 5 mm on an appropriate support inside a dark room, or so-called camera obscura. This method creates a two-dimensional "light" picture of reality, except the picture is upside-down, reversed and somewhat blurred. With the addition of single or compound lenses, however, the projected image can be sharpened, magnified or reduced, turned the right way up, and re-reversed. Concave mirrors can also project images that are still upside-down, but are not reversed. Even an ordinary lens from a pair of

spectacles, or a magnifying glass, can project an image of the outdoors without a pinhole. These images can be used as optical aids, which artists can use to study the logic of natural light, colour, perspective and shadow, or even as a way to arrange and rearrange a composition. As long as the daylight and image holds, artists can also easily outline the image with a pencil or brush, and interpret the colours as they appear on the image.

A substantial amount of art historical research exists which holds that the seventeenth-century Dutch artist Johannes Vermeer (1623–1675) used just such image projections as optical aids in his painting.¹ Yet the possible role of projected images in picture making before this time was little considered until 2001 when British painter David Hockney published his theory that these type of optical aids were employed extensively by artists long before Vermeer.

The thesis I am putting forward here is that from the early fifteenth century many Western artists used optics – by which I mean mirrors and lenses (or a combination of the two) – to create living projections. Some artists used these projected images directly to produce drawings and paintings, and before long this new way of depicting the world – this new way of seeing – had become widespread. Many art historians have argued that certain painters used the camera obscura in their work – Canaletto and Vermeer, in particular, are often cited – but, to my knowledge, no one has suggested that optics were used as widely or as early as I am arguing here (Hockney 2001:12).

Hockney's now quite expansively-debated thesis has been difficult for some art historians to accept. For example, "Columbia University professor of modern art and theory, Rosalind Krauss described *Secret Knowledge* as rank with 'the smell of paranoia and contempt for people such as herself'" (Berwick & Rosenberg 2002:38). Laurie Fendrich, Professor of Fine Arts at Hofstra University, has stated that optical explanations for the introduction of realism

could weaken the very underpinnings of the history of visual art, particularly the history of Western painting.

I think there are larger implications to Hockney's theory, assuming it is right, and that it will cause serious cultural damage. Let me begin with the idea that Hockney's theory is neither a big deal nor all that interesting. On the contrary, it shakes the foundations of much of art history, as well as realist painting as an art form. Learning that artists used lenses extensively in the 1400s shifts the "photographic" flat image from a minor, late-game player in Western art to a member of the starting lineup. ... More important it subverts the way that most of us look at and derive meaning from old-master paintings. And it subtly but profoundly alters what we who love Western painting think being human is all about (Fendrich 2002:3).

Some scholars, such as Krauss and Fendrich, have taken Hockney's pre-Vermeer theory to be provocative, and indeed it does challenge that human effort versus photographic easiness dichotomy. However, assumptions about skill and individual genius can be dangerously anachronistic, and in this thesis I try rather to concentrate on the art object as a way to uncover a deeper understanding of its conception. This is intended as a contribution to existing scholarship about medieval Italian art, and not some sort of replacement.

Nevertheless, although Hockney's thesis for a possible wide-ranging use of optics as early as 1430 appears novel to some researchers, he erred in believing he was the first to suggest that artists made use of the camera obscura before the time of Vermeer. For example, in 1990 Shigeru Tsuji put forward the notion that Filippo Brunelleschi (1377–1446) had used a camera obscura as an aid to the creation of his small panel paintings of the Baptistery and the Palazzo Signoria in Florence, and in 1994 Roberta Lapucci suggested that the Italian realist painter Caravaggio (1573–1610) made use of projected images. Lapucci stated that

Caravaggio's evolution in the use of mirrors moved beyond the traditional sixteenth-century practice, aimed at reproducing details and parts of the same model in one composition (the Metropolitan *Concert*), to the scientific innovation of using the camera obscura to reproduce the whole figure, thus allowing a work of art to be created directly from reality by placing colours onto a canvas while the figure was being projected (as in the Uffizi *Bacchus* and the Thyssen *Saint Catherine*). ... This method allowed the artist to create paintings with great speed, to copy faithfully from nature, and to reduce and enlarge the dimensions of figures with ease (Lapucci 1994; translated in Lapucci 2005:xvi).

Also in 1994, Nicholas Allen postulated that the so-called Turin Shroud was a type of photograph made as early as the mid-fourteenth century using photochemical techniques inside a camera obscura. At the time of writing his article Allen (1994:23) conjectured “that our current understanding of the level of scientific and artistic knowledge (technology) available in the medieval period (especially c. 1280–1357 AD) is in need of a major overhaul.”²

It is important to further note that prior to any modern research already in 1755 French publisher and writer Charles-Antoine Jombert (1712–1784) recorded a rumour that artists in Flanders commonly used the camera obscura, although he did not specifically name any. “With regard to the darkened chamber, we can remark that many Flemish painters (from what it is said) have studied and imitated in their paintings the effect it presents and the manner in which it makes one see nature” (translated and quoted in Delsaute 1998:123). While this remark has recently been linked specifically to the (Dutchman) Vermeer (Desaulte 1998:123), Jombert could, in fact, have meant any number of actual Flemish painters in the long tradition of their photographic-like realism, including Jan Van Eyck (c.1385–1441) in the early fifteenth century, a possibility promoted in particular by Hockney (2001:78).

A contemporary of Caravaggio, the Florentine artist Ludovico Cigoli (1559–1613), also considered the likelihood that image projections were a source of inspiration for “artful” painting.

[W]ith another more appropriate means nature reveals [pictures] in those narrow places into which light penetrates through a small hole, and within which a white surface is placed at a due distance; on this surface all of the images appearing from outside will be depicted, and the more the light that strikes them, the brighter will they be in color. But since they disappear when this device is removed I believe that some have had the idea, so as to conserve them, of applying colors to that surface, following the contours, drawing and painting those images. This seems more credible than what Pliny says about shadows, and projections of bodies, since a shadow shows only the outlines, while this shows not only the outlines but everything in the middle, with the greatest precision that can be desired in artful painting (translated and quoted in Camerota 2005:264).

In their current research Hockney, Tsuji, Lapucci, Allen and others reiterate a sentiment that goes back, therefore, to at least the time of Cigoli at the end of the sixteenth century. However, although some artists might have already been using projected images before the time of Vermeer, a more precise chronology awaits clarification. Hockney (2001:78) considers that projected images were first used by European painters around 1430 in Flanders, while Lapucci (1994:161) postulates an introduction of optical aids from about the mid-sixteenth century in Lombardy. For many reasons Lapucci’s starting date of the mid-sixteenth century is much easier to uphold than earlier dates, such as Hockney’s proposal of 1430. There was a proliferation of Italian texts around the sixteenth century concerning the camera obscura. For example, the Milanese mathematician and natural philosopher Girolamo Cardano (1501–1576) fully described how a camera obscura can make an image on a relevant support; in other words, the phenomenon reproduces a picture inside a

darkened chamber. In book four of *De Subtilitate* (1550) Cardano claimed that “to see what happens in the street when the sun is shining, put a glass disc on the window, then close the window, you’ll see the images and you will obtain in a wonderful way what you desire [that is, to see what is going on in the street]” (translated and quoted in Lapucci 2005:xviii). Caravaggio’s Lombardian teacher, Simone Peterzano (c.1540–c.1597), may have known Cardano through his friendship with Giovanni Paolo Lomazzo (1538–1600), an artist and theorist who certainly knew the Milanese mathematician (Ciardi 1973:192).

Then, in 1558 the Neapolitan philosopher Giovanni Battista Della Porta (1535–1615) positively recommended projected images as a way to assist drawing. In *Magiae Naturale* he instructed his readers to

[l]et sunlight, or images illuminated by the sun, through a window using a man-made hole; but not at the hole, but at the hole opposite place a white paper, and a sizeable part of a man will be accommodated in the light, bringing the image near and lengthening it, while you will see his perfect image, that you want placed onto the canvas, that which you want to paint, put colours onto the canvas, where [the image] appears, the face, the mouth, the eyes, and just as the figure appears, in this way leaving [an image] of the object, it will remain printed on the paper, and it can be seen in this way, just as it would be seen in a mirror (translated and quoted in Lapucci 2005:xix).

This sentiment was reiterated by the Venetian Daniele Barbaro (1513–1570) in his *La Prattica della Prospettiva* (1568).

Close all shutters and doors until no light enters the camera except through the lens, and opposite hold a piece of paper, which you move forward and backward until the scene appears in the sharpest detail. There on the paper you will see the whole view as it really is, with its distances, its colours and shadows and motion, the clouds, the water twinkling, the birds flying. By holding the paper steady you can trace the whole perspective with a pen, shade it and delicately colour it from nature (quoted in Naughton 2003).

However, to hypothesize that Italian artists first used a type of camera obscura only from the middle of the sixteenth century, as Lapucci has, ignores the place of Leonardo da Vinci (1452–1519) in Italian optical tradition. If not a user of the camera obscura in his painting, he was certainly a scientific experimenter who seriously considered the phenomenon of projected images (Pirenne 1970:24). Leonardo postulated that the eye works similarly to a camera obscura (Pirenne 1970:33–34). He also studied the images of sunlit objects (pictures), and not just the sun itself, and in order to capture the projection he used the opposite wall, or a very thin piece of paper held close to the aperture, which he looked at from behind (Pirenne 1970:33–34) In his *Treatise on Painting* he elaborated on what could have been a camera obscura with a concave mirror-lens, which was certainly illustrated thus by Nicholas Poussin (fig 1). As a friend of Cardano's father, Leonardo may have been a source for some of Cardano's work on the camera obscura in *De Subtilitate* (Collins 2000:558).

Hockney may therefore be correct in seeking to uncover an earlier starting date for the use of optical aids in western painting, and his claims cannot be simply dismissed, as some authors have done.³ It must be considered that manuscripts of the most famous Arabian medieval optical scientist Ibn al-Haytham (c.965–c.1040) became available in the Italian vernacular around the beginning of the fifteenth century. Lorenzo Ghiberti (1378–1455), a contemporary of Brunelleschi's, owned one such manuscript which he annotated extensively (Edgerton 1975:73). However, Al-Haytham used a pinhole camera obscura to study images of the sun and candlelight in a

scientific way, and did not write about the projection of *pictures* as such (Naughton 2003). All the same, Brunelleschi's experiments, possibly done with the aid of a camera obscura as postulated by Tsuji (1990), stimulated Leon Battista Alberti (1404–72) to synthesise the first Renaissance ideas about perspective. In 1435 Alberti published his theories in a treatise on painting *Della Pittura* (Kemp 1990:23). However, it must be considered that this activity was in Italy, and not in Flanders where Hockney places the first use of optical aids by artists, specifically with Jan van Eyck.

Hockney's theory for a 1430 starting date also relies too much on evidence seemingly obtained from a "wall" of coloured photocopies (Hockney 2001:4–9) which he claims shows a real and sudden shift in representation around the beginning of the fifteenth century (Hockney 2001:16–17), that is, from more stylised modes of representation to more realistic modes of representation. Through this experimental technique Hockney claims to be able to see that fifteenth-century artists were able to style portraits with observational skills of individualism that he does not witness in prior examples (Hockney 2001:66–67). Hockney further notes what he sees as a sudden interest in representing patterned cloth in a way that the pattern is shown to follow folds, and he also points to artists representing fine details such as the surface texture of armour, for example (Hockney 2001:38–45). However, as opposed to Hockney, I found other instances that, to my mind, show things differently. Certainly the work of the much-neglected medieval Sieneese artist Duccio di Buoninsenga (c.1260–1318) exhibits many of the "realistic" traits cited by Hockney, despite being executed more than a hundred years before the

1430 date. I therefore assumed that there was motive to look further back than this date for an introduction of optics, certainly as a way of explaining the shift in representation from medieval stylisation to more realistic and modern modes of depiction.

The writings of Tuscan biographer Giorgio Vasari (1511–1571) are also somewhat at odds with Hockney’s sentiments about a seemingly particular significance of fifteenth-century Flanders in the history of individuality in painting. In *Vite de Più Eccellenti Pittori, Scultori ed Architetti* (1550, rev. ed. 1568) Vasari stated that it was the medieval Florentine Giovanni Cenni de Pepo detto Cimabue (c.1240–1302) who specifically gave back “great lustre to the art of [Italian] painting” (translated and quoted in Bull 1965:49). Vasari’s sentiments about Cimabue, first expressed around 1550, have remained a more traditional way of explaining what is considered to be a fairly sudden appearance of a naturalistic representation seen also in the later work of Giotto di Bondone (c.1257/67–1337)⁴ and others.

Monica Chiellini (1988:5) rightly claims, for example, that what emerges of Cimabue “is the portrait of an artist who was able to establish through his work a new relationship between the onlooker and the painting.” She credits these changes to “stormy historical events and a spiritual crisis which shattered the existing ideological world into a variety of different self-interest groups; in the figurative world this called for new, different and even revolutionary solutions” (Chiellini 1988:5–6). However, although social and historical events might explain the “why” of a new onlooker/painting relationship, that is, an innovative attention to the nature of things, they cannot singly explain the

“how.” The “how” of individualism, in other words, how artists managed to invent a style that was more involved in an imitation of the individual subject or form, a closeness to the opticality of things, has been little theorised. Cimabue might explain Giotto, but what can explain Cimabue? Attempting to successfully answer this question is the essence of my thesis, which proposes that the use of projected images actually played a significant role in the introduction of individuality into Italian painting in the late thirteenth century. In other words, although humanism might explain *why* individualism developed, only by demonstrating the introduction of projected images at a crucial point in Italian painting is it explained *how* artists were able to introduce individuality into their work. I will show that this new individualism was based on a direct link between a developing scientific interest in optics on the one hand, and artistic changes on the other.

Some authors previously noted as a seeming coincidence this association between an emerging scientific attention to light and its qualities, and a new style of painting in Italy seemingly also based, in part, on light. For example, Paul Hills (1987:3) acknowledges that around “1250 and 1430 Italian artists rediscovered pictorial space and pictorial light,” yet he denies a direct link between this artistic phenomenon and similar discoveries which occurred simultaneously in the scientific environment. He therefore considers it highly unlikely that medieval artists in any way based their art on the progress of science (Hills 1987:64). Gary Radke (1984:35) also recognised that there may have been a certain papal role in the development of “illusionist” artworks in medieval Italy. He states that “... research by Paravicini Bagliani and Lindberg

has reached ‘the surprising conclusion that the papal court in Viterbo, in part fortuitously and in part through the activity of William of Moerbeke, served as a “centre” for the transmittal of optical literature in the 1260s and 1270s’ ... [where] a group of highly trained people around the pope, was interested in lenses and the mechanism of seeing” (Radke 1984:35–36). Radke (1984:35) points out that the works of Roger Bacon (c.1214–1294) ended up in the papal court, and notes how the Polish Dominican scholar Erazmus Ciolek Witelo (c.1230–1280) likely came to draw on the English scientist’s optical treatises, but he does not relate this directly to medieval Italian painting or painters, nor does he mention projected images or the camera obscura, and he remains sceptical of a “facile coordination of interests in optics” with the development of naturalism in Italian painting, although he continues to wonder “whether the precocious appearance of perspectival schemes in the art of papally patronized Rome in the period immediately following the Viterbese papacies is not in some way related to studies first encouraged in Viterbo” (Radke 1984:36).

Importantly, I will demonstrate that the connection between scientific development and a growing artistic awareness of the possibilities of realistic depiction was not merely “facile.” On the contrary, I show there must have indeed been an absolute connection between art and optics, and I demonstrate how Cimabue must have been one of the first artists to have had access to the practical and scientific experimentation with the phenomenon of light projections. What has been cited as naturalism cannot be overstated as medieval artists’ actual aim, however. Although Italian artists, seemingly from Cimabue onwards, began to record in their paintings what could be named as a

scientific rendering of the natural world, it appears that their art only inadvertently became more empirical, more observational, and less symbolic. Cimabue still maintained the spiritual significance of his paintings as holy icons. As Paul Barolsky states:

[n]aturalism is thus not an end in itself, but a stylistic means of rendering spiritual meaning. In Italian art of the thirteenth century and in the following period, it was employed as a means of depicting the transcendent subject (Barolsky 1997:57).

The result of using projected images was a more individualised depiction of people and objects, but subject matter remained Christian in its basis and models were chosen for their suitability as stereotypes. By way of example, Christ, the Apostles and the Church Fathers are uniformly portrayed with full beards, even long trailing ones, when the fashion of medieval times dictated that men be clean shaven (Goets 1938:61).⁵ I postulate, therefore, that it may have been a challenge to record the effects of projected images, not simply a humanist desire to represent people or objects more naturally, that changed the course of Italian painting. By referring to projected images Italian artists – particularly those whose art flowed from the cultured Tuscan environments of medieval Florence and Siena – appear to have been able to develop a style of painting that began to concentrate quite intently on individual characteristics and physiognomies, rather than on generalised and stylised illustration.

During the first half of the thirteenth century Italian painters were using formulas, graphic signs for the things being represented (a relatively more conceptual art), not the realities manifest in individual people and objects (a relatively more perceptual art). Towards the end of the thirteenth century Cimabue began to change this when he apparently became interested in a more

objective description of the human figure. I theorise that Cimabue's ability to move towards the creation of new, more individualistic modes of representation was given impetus by the introduction of specific optical systems into a stratum of Italian scientific culture, which then filtered into the visual arts of that time. Using the projected image, which is a vivid and colourful recreation of reality onto a two-dimensional plane, artists such as Cimabue found new ways of representation. I take as read, therefore, Cigoli's sixteenth century idea that "artful painting" (Cigoli translated and quoted in Camerota 2005:264) was based on projected images, and introduce to the debate a specific Italian artist and a specific date in Italian painting, to support this supposition. I do not deny, however, that other artists in other eras, or in other geographical regions, may also have used projected images, for example in Ancient Roman or in Ancient Greece, or in China.

It is my contention that the knowledge of projected images, that is the concept that *pictures* could be created with light on appropriate supports, came directly to Europe from China sometime around the middle of the thirteenth century. In fact, this practical application of the camera obscura (as a way to study pictorial effects, that is) must have come from China, as the Arab researchers like Al-Haytham were, seemingly, only interested in using the camera obscura for scientific observations such as studying eclipses, as has been stated. I realized that a medieval document dated to around 1250 and titled *De Mirabile Potestate Artis et Naturae et de Nullitate Magiae* (Davis 1992) (hereinafter referred to as *De Mirabile*), which has always been considered European (thus *Roger Bacon's Letter*), was actually Chinese in origin and is,

therefore, a crucial piece of evidence for the flow of ideas east to west. Perhaps because it is considered a sort of oddity it has been overlooked by researchers.

For example, Sarah Schechner, of Harvard University, claims that

[a]lthough medieval optical texts show that scholars were deeply interested in light, vision, mirrors, and reflections, [Charles] Falco is mistaken when he claims that passages from Witelo, Bacon, or Ibn al-Haytham offer evidence of the study of projected images from concave mirrors onto any screen. ... Their treatises were mathematical rather than practical. An inverted image viewed inside a shiny bowl was *not* understood by them as a *projection* in space between the eye and the bowl as we do today. ... Indeed, there is no documentary evidence for concave mirrors being used to project an image before the sixteenth century ... (Schechner 2005:139, author's original italics).

Schechner's statement is at odds with the wording in *De Mirabile*, which certainly contains the seminal idea that an image projection (a picture of real things "in the air," so to speak) can be created using mirrors (Davis 1992:29). Further, contrary to Schechner's supposition, both Bacon and Witelo do indeed describe image projections. In his *Opus Majus* (1268) Bacon expanded on the idea of image projections already proposed in *De Mirabile* (Burke 1928:581) and around 1270 Witelo added the concept that an actual painting of something could be made to appear somewhere else, in other words, that a camera obscura could be used in a way similar to a modern overhead projector (Hockney 2001:206).

I will proceed, therefore, to demonstrate in detail my seemingly unique contention that "Roger Bacon's letter" could not have been written by him. Rather it was likely addressed to him, almost certainly from a source in China, as will be explained. It was probably penned by the medieval monk Giovanni da Plano di Carpini (c.1180–1252), who travelled to Mongolia between 1246 and 1247. This then makes sense of the optical description in the *De Mirabile*

letter, which finds its proper place within a much older Chinese tradition. For example, the early medieval Chinese statesman and philosopher Shen Kua (c.1031–1095) described an inverted reversed image which forms on a wall or a support opposite a small hole in a dark room (Needham 1962:97). His research rested entirely on the much older Mohist tradition in China (Needham 1962:98).

The mention of the passage in the *Yu-Yang Tsa Tsu*, written by Tuan Chhêng-Shih early in the +9th century, brings up the question of the antiquity of the study of the pinhole and camera obscura. *Mo Ching*, ... has already shown us that the Mohists about –300 were familiar with the former; now we see that inverted pagodas were being looked at at least as early as about +840. Yet the earliest work with the camera obscura is usually attributed to Ibn al-Haitham [Alhazen], the great Arab physicist ..., when not put down to the 16th- and 17th-century people such as della Porta or Kircher. There can be little doubt that both the Chinese and the Arabs were interested in [the camera obscura] ... from the +8th century onwards, and the full unravelling of the story must be left for further research (Needham 1962:98).

This ancient knowledge of image projections first became known in Italy in 1268 when Roger Bacon's *Opus Majus* arrived with a special courier in Viterbo, the then papal seat. The package included an actual lens, which Bacon encouraged the pope to experiment with (Goldstone & Goldstone 2005:142). It is uncertain whether Clement IV (Guy Foulques le Gros born c.1195), who also died in 1268, ever got to see the *Opus Majus*, but major parts of the section on optics were enthusiastically copied by Witelo (Goldstone & Goldstone 2005:142). Shortly afterwards Cimabue also arrived in the papal region and is documented in Rome in 1272 (Tomei 1997:48). Described as "*Cimabue picture de Florentia*," (Tomei 1997:48) he was called as a witness to Pope Gregory X's assumption of the patronage of the monastery of San Damiano. This establishes the possibility of a direct causal link between

Cimabue and the knowledge of projected images, and indeed neatly explains the sudden appearance of Cimabue's (previously inexplicable) individualistic *Crucifixion* (c.1272, plate 1) from the Church of San Domenico in Arezzo. This new style of crucifix heralded a flowering of detailed naturalism in Western painting at the end of the thirteenth century that coincided absolutely with the arrival of Roger Bacon's *Opus Majus*. In fact, certain Tuscan paintings from between 1270 and the beginning of the fourteenth century show evidence of an intense flirtation between art and optics at this time.

Before turning directly to the optical evidence, which I believe can be found in the artworks themselves, and to the art historical documentary evidence such as there is, in chapter one I therefore focus on the history of science in general, and the history of optical science in particular, to show how medieval Europeans gained knowledge of the ancient Chinese understanding of projected images, specifically as a way of casting pictures of the outside world inside a darkened room. Because it is certainly easy enough to dismiss medieval texts that refer to projected images as vague and meaningless, as Schechner (2005:139) has done for example, a thesis that promotes medieval artists' use of optical aids, such as the camera obscura, cannot progress without first showing exactly how Roger Bacon might have come by some of his practical optical ideas, and how these ideas thereafter could have fallen into the hands of certain medieval Italian painters.

Chapter one follows a deductive method. I begin by deconstructing "Roger Bacon's letter," which, as I have stated, has always been assumed European, and show how it appears quite glaringly Chinese in origin. As

foundation for my research I have notably relied on certain publications (particularly *Science and Civilization in China Vol. IV: physics and physical technology*) of the Cambridge University scholar and biochemist Sir Joseph Needham, one of the most authoritative Sinologists of modern times. I hope, in this way, to establish with certainty that the reference to the arrangement of mirrors in *De Mirabile* (Davis 1992:29) refers directly to an image projection. In this way I also, I believe, make a significant contribution to the “unravelling of the story” of the camera obscura, called for by Needham (1962:98). In chapter one I strengthen my assumption for the start of an optically-based painting at an earlier date than that of 1430 by demonstrating the injection of Chinese technology at a specific time and specific place in the history of European science. Practical knowledge was far more important, certainly to artists, than the later addition of theoretical posturing, such as Al-Haytham’s scientific treatise. Bacon, in any case, seems to have discovered Al-Haytham’s treatise only sometime after he came into possession of the *De Mirabile* letter.⁶ Further, I also highlight that although China never experienced a (theoretical) scientific revolution as was seen in Western Europe, nevertheless the practical nature of technologies found in medieval documents like *De Mirabile* appear to have contributed significantly to the development of science in Western Europe in a number of disciplines, not just optics. Certainly Chinese technology was considerably advanced over that found in medieval Europe around 1250.

In chapters two and three I look directly at Cimabue and Duccio who I believe were among the first medieval Italian artists to use image projections.

It is crucial to reiterate that the phenomenon of the projected image is not restricted to those images which can be seen as the result of a pinhole allowing coloured light into a darkened room or chamber. Although Hockney most specifically talks about “optics” in relation to his own theory – and he clarifies this to mean projected images produced by both mirrors and lenses – there has been a tendency to elide this definition with the more blanket term “camera obscura.” This unfortunately has led to the assumption that artists were only using pinhole images (with or without the addition of a lens). As part of my methodology therefore, I must clarify this confusion by introducing certain, relatively simple, optical problems into the nature of my experimentation. Nevertheless, because the visual results tend to be similar, it is not the intended scope of this thesis to establish the exact optical aids employed by individual artists, or to discover with certainty whether they were using concave mirrors or converging lenses of specific dimensions. I will show that medieval artists, those who were using projected images, appear to have concentrated in their work on certain optical effects, for example, as a way to trace outlines for correct human proportions. However, Duccio also interpreted the coloured light as well, noting in a unique way the peculiarities of light as it can be interpreted at different times of the day. Nevertheless, this does not mean that I believe Duccio would have been restricted to working on individual subjects at specific times of the day, as that which could be called “photographic shadowing” is not a key element of his work.

With regard to art historical methodology I rely on a close, optically-aware reading of available early literature, such as *The Craftman’s Handbook*

(late fourteenth century) by Cennino d'Andrea Cennini (dates unknown) and Vasari's *Vite de' Più Eccellenti Pittori, Scultori ed Architetti*. Further, to reinforce my theory it has been necessary to invent methods of studying the paintings under consideration in ways that have not been employed previously by historians of medieval painting. In developing certain experiments I have relied on Charles Falco's pioneering research (2000 onwards), which has given Hockney's art historical thesis a scientific basis in trialling precise computer-assisted optical measuring techniques. Continuing with the art historical precedent of scanning the surface of the image I have worked out a method of analysing digital images using a wide range of "virtual" tools available in the computer graphics package CorelDRAW. This very specific inductive experimentation offers, to future researches, the means to rigorously repeat and test the assumptions of this thesis. Using this methodology I have also been able to present a strong case for the possible re-attribution of two significant medieval works that otherwise remain somewhat inexplicable. These are a *Crucifix* (c.1299–1303, plate 25) in the Church of Santa Maria Novella in Florence, which is commonly attributed to Giotto (Zuffi 2006:11), but which I strongly recommend should be considered as a work of Duccio, and a *Crucifix* (c.1272–1280, plate 6) in the Church of San Domenico in Bologna, which has recently been attributed to Giunta Pisano (active early thirteenth century) (Chiellini 1998:11), but concerning which I suggest the reattribution of the central figure of Christ to Cimabue, and a dating of c.1270–1280. The details of these proposals are found in chapter three.

Although I refer to my computer-assisted method throughout the text from chapter two onwards, in the interest of absolute clarity I also present the experiments in full detail in the Appendix, replacing the need for expansion in copious endnotes. I hope that these experiments will contribute to further developments in computer-assisted ways of studying art works.

In addition to the computer-assisted experimentation I have also conducted extensive real life experiments. This involved “building” cameras obscura (darkening suitable rooms) and testing different lenses, for example, concave mirrors, biconvex lenses and compound-lens systems. These experiments are also recorded in the Appendix. While researching this thesis I was able to travel to Tuscany to see first hand the paintings under consideration. I went to Arezzo to study Cimabue’s crucifix, to Assisi to see the frescoes of both Cimabue and Giotto, and to Siena to look closely at Duccio’s *Maestà*. I also visited the Uffizi in Florence, and spent a great deal of time examining the three Madonna altarpieces that I consider central to this thesis – Duccio’s Rucellai *Madonna* (1285, plate 13), Cimabue’s Santa Trinità *Madonna* (1285, plate 14) and Giotto’s Ognissanti *Madonna* (1310, plate 15).

In chapter three I focus more closely on the artistic relationship between Cimabue and Duccio. The geographical situatedness of Cimabue and Duccio must be taken into consideration, as Cimabue was Florentine and Duccio Sienese. The Florentine Vasari thought that Duccio’s Rucellai *Madonna*, for centuries a chapel piece in the Church of Santa Maria Novella in Florence, had to be the work of a Florentine and he therefore chose Cimabue. Optical theory

can help to explain why this painting, despite being by a Sieneese, held the Florentine imagination for so long. Further, optical theory can also better explain the stylistic relationship between Duccio and Giotto, and the later development of Italian painting into two distinct traditions of colour-orientated individualism and form-orientated naturalism. Here I need to clarify my choice of the term “individualism” over the more usual term of “naturalism.” The concept of “individuality,” as a way of describing paintings that seemed optical, was first used, briefly, by Hockney (2001:67). In some respects “natural” and “individual” are interchangeable, but the words are not strictly synonymous. In the presentation of this thesis I felt it was necessary for the field of art and optics to define and carefully demarcate a category of its own, and hence I use the term individuality/individualism to describe the way Cimabue and Duccio, in particular, began to look at the projected image, and to translate this vision into the painted artifact. Finally I briefly contextualise the Tuscan artistic experience of optics, and show how this influenced a broader Italian development of individualism.

My thesis clarifies the long-held but inexplicable Vasarian tradition that “although [Cimabue] ... retained the old Greek manner, one forever sees that he possessed the way and the features of the modern” (translated and quoted in Bull 1965:50). What has been unrecognised until now is that evidence of Cimabue’s individualism is found in works dated as early as 1270, and that the little-known San Domenico Arezzo *Crucifix* is based quite pointedly on what Fendrich called the “‘photographic’ flat image” (Fendrich 2002:3). In a sense I show how we have come full circle: when we study a photograph of

Cimabue's medieval *Crucifix* in a book, or digitally on a screen, we are looking at a photograph of a painting created from a "light drawing," that is, from a photograph.

¹ For example, see Hyatt Mayor, A. 1946. The photographic eye. *Metropolitan Museum of Art Bulletin (New Series)* 5(1):15–26; Seymour, C. 1964. Dark chamber and light-filled room: Vermeer and the camera obscura. *The Art Bulletin* 46(3):323–331. Mills, AA. Fink, DA. 1971. Vermeer’s use of the camera obscura: a comparative study. *The Art Bulletin* 53(4):493–505; 1998. Vermeer and the camera obscura: some practical considerations. *Leonardo* 31(3):213–218.

² Although the Shroud is considered by some to be the actual image of Christ, others think of it as a painted object.

³ David Stork, then a Consulting Professor of Electrical Engineering at Stanford, mounted a personal campaign to discredit this particular claim of Hockney’s. He presented a paper in 2002 titled “Optical rebuttals to Hockney’s explanations of ‘opticality’ in early Renaissance painting” (Stork 2002). He continued his assault on the Hockney thesis, alerting the press in August 2004 to the release of a paper he had written together with Cambridge computer expert Dr Antonio Criminisi (Criminisi & Stork 2004). Articles appeared in the *New York Times* and the *Sunday Herald* (Boztas 2004). Stork then published a further rebuttal paper, “Optics and realism in Renaissance art,” which appeared in *Scientific American* December 2004.

⁴ The usual birthdate for Giotto is given around 1267. However, Bologna points out the following: “Some time ago Ragghianti drew attention to an unpublished document that had been brought to his notice by such authorities on the Florentine archives as Poggi and Procacci, in which a son of Giotto’s name Francesco is mentioned as a ‘priest’ in 1301 (which means he must have been born not later than 1280), while Giotto’s father Bondone appears to have been comfortably off in 1220. If these dates are confirmed, that of Giotto’s birth must be put back at least ten years to 1267 [that is, to 1257], the date usually accepted” (Bologna 1983:339).

⁵ This means that an artist, using a model who was clean shaven in the fashion of the day, would have had to make up a beard, or encourage the model to grow one for the duration of his employment with the artist.

⁶ As Robert Grosseteste had no access to Al-Haytham it can be assumed that Bacon cannot have become familiar with the Arab’s optical treatises until at least after Grosseteste’s death in 1253 (Lindberg 1974:392), therefore after he first came into contact with the stimulation of Chinese technology, rather than Arabic theory, certainly in my opinion.

CHAPTER 1

Roger Bacon and the projected image

1.1 DOCUMENTARY EVIDENCE

Sometime around 1556 the medieval document *De Mirabile* was acquired by the enigmatic Elizabethan alchemist and statesman Dr John Dee (1527–1609) (Goldstone & Goldstone 2005:180). Dee considered that Roger Bacon was the author of this letter and he therefore published it in Oxford in 1594 as *Epistola Fratris Rogerii Baconis de Secretis Operibus Artis et Naturae, et de Nullitate Magiae* (*Friar Roger Bacon's Letter Concerning the Marvelous Power of Art and of Nature and the Nullity of Magic*) (Kent 1978:146).¹ Recorded in this letter was the intimation that an image can be created using mirrors.

Mirrors may be so arranged that a man coming into a house shall really see gold, and silver, and precious stones, and whatever a man desires, but whoever approaches the place will find nothing (translated and quoted in Davis 1992:29).²

The author of *De Mirabile* saw this seeming conjuring device as allied to many other optical devices he knew of and considered “especially marvelous” (translated and quoted in Davis 1992:28), among which was one piece of glass that could be used with violent effect.

But of sublimer powers is that device by which rays of light are led into any place that we wish and are brought together by refractions and reflections in such fashion that anything is burned which is placed there. And these burning glasses function in both directions, as certain authors teach in their books (translated and quoted in Davis 1992:29).

These so-called “burning glasses” could be a reference to concave mirrors that both reflect and refract light, as they will “function in both directions.” The idea

a lens could refract and reflect light was a most advanced concept. As Baig (1982:29) points out, medieval authorities, like the Englishman Robert Grosseteste (1168–1253), studied the reflection and refraction of light as separate phenomena. It was not generally understood that a concave mirror also refracts light and can thereby *project* an image *in the air*, the spectre of which can be made to disappear so that, in the words of *De Mirabile* quoted above, “whoever approaches the place [of the projection] will find nothing.” Despite this, modern scholars, such as Sarah Schechner (2005:139), maintain there was absolutely no description of the lens capabilities of concave mirrors before the sixteenth century.

Also in *De Mirabile* is the suggestion that optical devices can be arranged in ways that have telescopic or microscopic effects, a concept that was supposed to have been understood only from the sixteenth century.

We may read the smallest letters at an incredible distance, we may see objects however small they may be, and we may cause the stars to appear wherever we wish. Devices may be so contrived that the largest objects appear smallest, that the highest appear low and infamous, and that hidden things appear manifest (translated and quoted in Davis 1992:28).³

In fact, *De Mirabile* contains many wondrous ideas which can only be considered highly advanced for the time period, listing a string of post-Renaissance concepts and even inventions that can be considered post-Industrial Revolution.

It is possible that great ships and sea-going vessels shall be made which can be guided by one man and will move with greater swiftness than if they were full of oarsmen.

It is possible that a car shall be made which will move with inestimable speed, and the motion will be without the help of any living creature.

It is possible that a device for flying shall be made such that a man sitting in the middle of it and turning a crank shall cause artificial wings to beat the air after the manner of a bird's flight.

Similarly, it is possible to construct a small-sized instrument for elevating and depressing great weights, ... [and] a man may ascend and descend, and may deliver himself and his companions from peril of prison, by means of a device of small weight and of a height of three fingers and a breadth of four.

It is possible also easily to make an instrument by which a single man may violently pull a thousand men toward himself in spite of opposition, or other things which are tractable.

It is possible also that devices can be made whereby, without bodily danger, a man may walk on the bottom of the sea or of a river. ...

These devices have been made in antiquity and in our own time, and they are certain. I am acquainted with them explicitly, except with the instrument for flying which I have not seen. ... But I know a wise man who has thought out the artifice (translated and quoted in Davis 1992:26–27).

The author of *De Mirabile*, along with his claim for being able to create projected images, alleged also to have seen huge, single pilot ships, mechanical cars, and even a type of underwater suit, and also professed to be familiar with the idea of flying machines.

Furthermore, in the appendix to *De Mirabile*, under the title “The Philosopher’s Egg,” there appears to be a coded recipe for gunpowder (Goldstone & Goldstone 2005:108). This formula was uncovered in 1914 by a retired British army officer and amateur cryptographer Colonel Hime, using an Argyll cipher template placed over the final section of the letter (Goldstone & Goldstone 2005:108). The existence of a recipe for gunpowder in a document dating from 1250 is further evidence that *De Mirabile* was unlikely to have been

written by Roger Bacon. Knowledge of how to make gunpowder appears to have spread from China into Arabia sometime during the twelfth century, but was unknown in Europe before the dating of the *De Mirabile* letter (Burke 1927:83). It is certainly seems impractical to think that someone with Roger Bacon's background at that time would have conceived of such information himself.

De Mirabile exhibits a certain familiarity with the Greek philosophers, for example Aristotle (Davis 1992:25). This sort of cursory knowledge of the ancient philosophers would have been common amongst monks like Carpini and Bacon. Bacon in fact specialised in Aristotle, that is, what was available translated into Latin from Arabic, not the original Greek, by scholars working in Toledo after its fall to European rule towards the end of the eleventh century (Goldstone & Goldstone 2005:26). Bacon was called to Paris to teach about Aristotle and until around 1250 he actually showed scant interest in science and technology, such as the engineering and optical devices outlined in *De Mirabile* (*MacTutor History of Mathematics Archive* 2008. Sv. "Bacon"). Even up until 1266, at which time he began to compose his *Opus Majus*, he had written very little of a systematic nature (Davis 1992:8).

Bacon's formal education included little (if any) natural science, and he did not undertake a serious study of the more mathematical and technical sciences – such as optics – until after he had terminated his teaching career in the faculty of arts at Paris (between 1247 and 1250) and returned to Oxford (Lindberg 1971:67).

He therefore lacked the sort of background one might expect from someone who supposedly dreamt up the many wonders in *De Mirabile*. Nevertheless, Bacon has been considered “[s]o far in advance .. of his own age ..., that Whewell in

his ‘Philosophy of the Inductive Sciences’ is moved to remark ‘I regard the existence of such a work as the “Opus Majus” at that period [1268] as a problem which has never been solved”’ (Burke 1927:80). In consequence, should we continue to uphold the myth of Bacon’s penmanship of *De Mirabile*, we must believe that not only did he (an ordinary teacher of medieval translations of Aristotelian tracts) somehow come up with a formula for gunpowder *and* work out how mirrors form image projections, but he also added a list of many other marvels unheard of in Europe until then.

In the light of this, it might be tempting to dismiss *De Mirabile* as a curiosity, or even a fraud. Certainly, modern scholars like Schechner simply turn a blind eye to the possible references of projected images achieved by concave mirrors as far back as 1250. A. Mark Smith, of the University of Missouri, Columbia, also states categorically that, in his opinion, knowledge of how mirrors projected images was unknown until much later.

We know that spherical concave mirrors, as well as spherical convex lenses, were readily available long before [1430] We also know that long before then the science of optics had reached a high level of technical perfection within the so-called Perspectivist tradition, whose foundations were laid in Alhacen’s *De aspectibus* – a soup-to-nuts treatment of optics in seven books. Indeed, at the hand of Alhacen and his Perspectivist followers ray-geometry and experiment had become powerful tools of optical analysis. Surely, given the availability of the requisite technical resources and knowledge by the turn of the fifteenth century, someone at the time besides artists should have noticed that concave mirrors and/or convex lenses cast real images. Yet, as far as we know, no one did (Smith 2005:164).⁴

Schechner and Smith blatantly ignore China, and what is generally called the “Chinese theory.” They also ignore Joseph Needham, who brought the history of early Chinese science and technology to the attention of the world, beginning with the first volume of *Science and Civilization in China* in 1956. Needham

published seven volumes in all, which eventually ran to thousands of pages. Writing excitedly at the time of the first volume's publication, Kenneth Rexroth (1956) pointed out the value of Needham's contribution and how this would eventually redress an imbalance in the writing of the history of western science.

Too much of the chauvinistic struggles for 'firsts' prevails in the history of science. ... [but] Needham has no need to be controversial. He has the evidence. The Chinese were the first accurate astronomical observers anywhere before the High Renaissance. ... The Chinese first discovered a sculling oar, essentially a propeller, and had treadmill-operated paddle wheel vessels at least as early as the fifteenth century AD. Chinese junks were the first to have rigging that would sail into the wind, and the first sternpost rudders. As is well known, the Chinese were the first to use the mariner's compass, ... The list goes on – the wheelbarrow, porcelain, silk technology, the mill wheel, the paddle wheel, paper making, the windmill, gunpowder, cast iron (perfected by the Chinese before the Christian era), printing from movable types, the iron chain suspension bridge, deep well drilling, an efficient horse harness and the modern horse collar, ... [and so on] (Rexroth 1956).⁵

The Chinese were also significantly advanced on the Europeans in optics, a field covered by Needham in his fourth volume of *Science and Civilization in China: physics and physical technology* (1962). What struck me about Needham's vast work is that so much of the technology he touts as being Chinese "firsts" are, in fact, written about quite evidently in *De Mirabile* – the effects and uses of lodestone, gunpowder, huge ships that could be steered by one man, as examples.⁶

For example, it has only been acknowledged in recent times that China was significantly advanced in ship design and maritime power in the Middle Ages (Lo 1955:489). If *De Mirabile* can indeed be dated to around 1247, then at this time northern Europeans were still sailing longboats, as even the slightly more sophisticated cog, with its stern-mounted rudder, can really only be firmly dated towards the end of the thirteenth century (Anderson 2003:87). Northern-

European vessels, which were little more than tubs, were square-rigged with one mast, reached around 20 metres in length, and displaced an average of 25 tons (Friel 1995:35). On the Mediterranean the Europeans favoured lateen-rigged galleys, which displaced around 80 tons and were on average about 40 metres, and were not suited to deep-water sailing (Friel 1995:109–115).⁷ On the other hand, Chinese vessels were far advanced.⁸ By the Sung Dynasty (the tenth to the thirteenth century) they were generally 120 metres in length, were already multi-masted, had stern-mounted rudders and displaced an average of 120 tons (Levathes 1994:43).

By the early thirteenth century the Chinese had the best boats in the Indian Ocean and had captured the bulk of the sea trade from the Arabs. The average oceangoing merchant junk was about 100 feet long and 25 feet wide at the beam, and carried 120 tons of cargo and a crew of 60. The large ships carried three hundred tons and five to six hundred people and towed lifeboats (Levathes 1994:43).

By the time of the Yüan Dynasty (thirteenth and fourteenth century) the Chinese were building even larger vessels (Levathes 1994:79).⁹ Medieval Chinese junks could certainly have been described by an awe-inspired contemporary European traveller as “great ... sea-going vessels ... which can be guided by one man and ... move with greater swiftness than if they were full of oarsmen” as in *De Mirabile* (translated and quoted in Davis 1992:26). Northern European vessels of the fourteenth century are recorded as moving at a relatively slow speed of around 1 knot (1 nautical mile per hour), making about 24 nautical miles a day (Friel 1995:85). On the other hand, junks of the Chinese Ming Dynasty (fourteenth to seventeenth centuries) could cover a hundred nautical miles a day at an average speed of 4 knots (Menzies 2003:120).

Despite Needham's prodigious contribution to western knowledge of the history of Chinese science and technology, many occidental scientists fail to mention the possible influences of China when considering the history of science in Western Europe. Enigmas, like the authorship and authenticity of the medieval letter *De Mirabile*, are left unquestioned. Before the accepted date of the *De Mirabile* letter, that is around 1250, Europeans had only primitive technologies in many respects. For example, as has been mentioned, they were sailing small boats that had changed little for thousands of years, and there were no boats with the convenience of a stern-mounted rudder in Western Europe before 1250. There simply are no indisputable sources in Europe, or even in classical Greek and Roman literature, for the *De Mirabile* letter. The origins of this letter therefore becomes a crucial piece of the puzzle, and must be explained if the history of European optical science, and what transpired in Italian painting as a result of this, is to be better understood.

1.2 THE ORIGINS OF "ROGER BACON'S LETTER"

We know that the *De Mirabile* letter, possibly the original, was among the items obtained by John Dee when he began buying up originals and copies of Roger Bacon's writings (Goldstone & Goldstone 2005:180). These writings had been assigned to various dusty, dank vaults in monasteries around England after he died (Goldstone & Goldstone 2005:173). Only a very few of the original manuscripts survived, but some were copied in the fourteenth and fifteenth century by small groups of students who endeavoured to keep Bacon's research

alive (Kent 1978:28). However, it was not until the early sixteenth century that Bacon was to be rescued from relative obscurity by the enigmatic John Dee, who, while still a student at Cambridge University, developed something of an obsession for the medieval monk's work (Goldstone & Goldstone 2005:174). As has already been mentioned, the letter *De Mirabile* was acquired by Dee sometime around 1556. It was from this point that *De Mirabile* began to be considered under Bacon's authorship, often thereafter called "Roger Bacon's letter." Much speculation still goes into the supposed intended recipient, as well as the motivation for Bacon apparently writing the letter. As far as Bacon's background is concerned, it is considered that he may have sourced many of his optical ideas from Robert Grosseteste. This theory has serious limitations however, as even Grosseteste's optical theories were comparatively archaic.

Although Robert Grosseteste greatly stimulated European interest in optics, his own investigations were hampered by the lack of many important sources. Ptolemy's *Optica* was just becoming known in the West, and it is doubtful that Grosseteste was familiar with it; Alhazen's *Perpectiva*, although translated [into Latin] late in the twelfth or early in the thirteenth century, had not come to Grosseteste's attention by the time he composed his optical works. Consequently, Grosseteste's knowledge of optics, though more complete than that possessed by any Western predecessor or contemporary, was primitive by comparison with the optical achievements of Islam; thus his works lack the scope and depth of such a work as Alhazen's great optical treatise, as even the most casual inspection will reveal (Lindberg 1974:392).

Therefore, as Al-Haytham's more advanced scholarship seems to have come to Bacon's attention only after Grosseteste's death in 1253, neither Al-Haytham nor Grosseteste can have been undisputed sources for the optical references in *De Mirabile*.

Looking for other scientific or technological mentors, further authors have turned to Peter Peregrinus, also known as Pierre de Maricourt, an engineer in the

army of Charles I of Anjou. It is claimed that Peregrinus's scientific research was responsible for stimulating Bacon's interest in mathematics and natural philosophy while he was still teaching in Paris in the 1240s (*MacTutor History of Mathematics Archive* 2008. Sv "Peter Peregrinus"). Certainly, Bacon later recorded his praise for Peregrinus, yet little is known of this Frenchman before the appearance of a mysterious letter on magnetism, *Epistola Petri Peregrini de Maricourt ad Sygerum de Foucaucourt, Militem, de Magnete*, or more commonly *Epistola de Magnete*, dated to around 1269 (*Encyclopaedia Britannica* 2005. Sv "Peregrinus of Maricourt, Peter"). Needham judged this "important treatise on the magnet ... one of the finest contributions to physics of the whole of the medieval period" (Needham 1962:246). However, if Peregrinus was the author he seemingly wrote nothing else, or nothing survived. The *Encyclopedia Britannica* claims that the Peregrinus theory of magnets provided

... the first extant [European] written account of the polarity of magnets (he was the first to use the word "pole" in this regard), and he provides methods for determining the north and south poles of a magnet. He describes the effects magnets have upon one another, showing that like poles repel each other and unlike poles attract each other. In the second part of his treatise he treats the practical applications of magnets, describing the floating compass as an instrument in common use and proposing a new pivoted compass in some detail (*Encyclopaedia Britannica* 2005. Sv. "Peregrinus of Maricourt, Peter").

The concept of a pivoted compass cannot be claimed as "new" however, only new to Europe. Although the floating compass was known in Europe from around the end of the twelfth century, and was mentioned by Alexander Neckham in 1190, the then unknown dry pivoted compass was already in use in China from the mid-twelfth century (Needham & Ronan 1978:9). The eleventh century Chinese philosopher Shen Kua experimented and puzzled in a detailed

way over the phenomenon of lodestone and the attraction of iron, as well as examining the action of the compass.

Magicians rub the point of a needle with the lodestone; then it is able to point to the south. But it always inclines slightly to the east, [that is, what we now call magnetic South] ... (It [the needle] may be made to) float on the surface of water, but it is rather unsteady. It may be balanced on the finger-nail, or on the rim of a cup, where it can be made to turn more easily, ... (translated and quoted in Needham 1962:250).

A pivoted compass made out of wood in the shape of a turtle, consisting of lodestone and a needle, was described in a diagram in the Chinese text *Shih Lin Kuang Chi* in c.1150 (Needham 1962:257).

That Peregrinus and Bacon were acquainted, specifically around the crucial date of 1247 when Bacon somehow came into possession of the *De Mirabile* letter, could suggest that a common source stimulated their later scientific interests. That Peregrinus and Bacon both wrote treatises that elaborated technology already well known in China, supports the supposition that this knowledge came directly from China at this time. It should be noted that the author of *De Mirabile* makes specific mention of the magnetic properties of lodestone, stating that “[t]here are many wonders of Nature which are not known to the crowd in this attraction of iron, as experience teaches the solicitous enquirer” (Davis 1992:31). Certainly, by around 1270 Peregrinus was able to publish a treatise on magnets that contained much new information unknown to the “crowd” until then.

That scholars of the medieval era continue to insist on Bacon’s authorship of this *De Mirabile* letter, full as it is of allusions to specific medieval Chinese technologies, is undoubtedly the result of a certain Eurocentrism, which has not changed since the nineteenth century.

Much of the dissatisfaction of modern historians of science with what have sometimes been called “the Chinese claims” has arisen from an inability to recognise the legendary component in the early Chinese references to the south-pointing carriage. ... There has also been the usual tendency to presuppose that nothing of real importance could have started outside Europe; thus in 1847 Whewell opened his discussion by saying, patronisingly, “Passing over certain legends of the Chinese, as at any rate not bearing upon the progress of European science ..”; though neither he nor anyone else succeeded in finding any precursors of European knowledge of the lodestone’s directivity before the turning-point of +1190 (Needham 1962:229–30).

Modern references to what is now called “Roger Bacon’s letter” therefore repeat the shaky sentiment that the letter, influenced by either Grosseteste or Peregrinus, was written by Bacon around 1250, and was destined either for William of Auvergne (d.1248) or John of Basingstoke (d.1252) (*Literary Encyclopaedia* 2004. Sv “Bacon”). Yet nothing significant is known of John of Basingstoke, and William of Auvergne, as Bishop of Paris, was a theologian inclined to condemn those parts of Aristotle that did not accord with Church teaching, making him an unlikely recipient for such a letter (*Encyclopaedia Britannica* 2005. Sv “William of Auvergne”).¹⁰

Bacon went to Paris in 1241 to teach Aristotle at the university. Six years after arriving in Paris he then left, quite suddenly, of his own accord.

... Bacon made the decision to reject Paris and everything it stood for – the politics, the close-minded rigidity of the theological faculty, the absence of that intangible spirit of discovery that had characterized his early studies. He chose instead to seek knowledge on his own (Goldstone & Goldstone 2005:98).

Coincidentally, round the time Bacon went back to Oxford, one of the first medieval European envoys to the Far East arrived back in France. Italian Franciscan Giovanni da Plano di Carpini returned to Europe after a two year journey to the outer reaches of Khanate Mongolia. Carpini had left in 1245 from

Lyon, and is recorded as reaching Karakorum on July 22, 1246. He remained near the capital for three months, before turning around and making his way home. Although Carpini does not record going to Peking (Beijing), he was able to describe the physiognomy of its people. He stated “[the Chinese] ... have no beards, and they agree partly with the Mongols in the disposition of their countenance” (translated and quoted in Komroff 1928:15). He therefore must have met Chinese people on his journey.

Carpini had gone to the Far East under the instructions of Pope Innocent IV shortly after the first Council of Lyons in 1245 (Speake 2003:191). Robert Grosseteste, as Bishop of Lincoln, attended the same council, along with two hundred and fifty other prelates (*MacTutor History of Mathematics Archive* 2008. Sv “Robert Grosseteste”). Bacon, who always greatly admired Grosseteste, might have known him personally as they were both Oxford educated (Clegg 2003:57–58). Further, in his *Opus Majus* Bacon refers directly to Carpini, and he had direct access to Carpini’s report of his travels written for Pope Innocent (Burke 1928:386).

Certainly, it was at this juncture that Roger Bacon’s life changed drastically. Quitting Paris in 1247 and retiring from university life, as has already been stated, he managed to get through a family fortune in the space of less than ten years, money he says he invested “on the study of wisdom, after abandoning the usual methods, ... on secret books and various experiments, and languages, and instruments, and mathematical tables, etc” (translated and quoted in Goldstone & Goldstone 2005:101). He put the sum he spent at £2000, which in today’s terms equates to £10 million sterling (Clegg 2003:38).¹¹ Bacon’s

horizons expanded dramatically and from being a plain teacher of Aristotle, he set about becoming a (medieval) world authority in a wide-ranging area of expertise: from optics, mathematics and astronomy, to cartography and world geography.

Bacon seemed to acquire an inexplicable knowledge of the seas and world geography for someone who would have crossed the English Channel around 1241 in an inconvenient and small European long boat.¹²

Bacon's individual inspirations are remarkable enough. When Christopher Columbus wrote to Ferdinand and Isabella of Castille to win their support for his voyages of exploration, he unknowingly used Bacon's work to promote his cause. Columbus thought he was quoting the French Cardinal Pierre d'Ailly, but the section of d'Ailly's book he found so impressive was lifted word for word from the writings of Roger Bacon. Armando Coresão, the respected Portuguese historian of map-making, comments that Bacon's work was "exceptionally significant" in moving away from the stylised maps of his time to ones that used a true map projection, the first such for over a thousand years (Clegg 2003:1–2).

Bacon certainly believed the world was round.

Seven hundred years ago the Earth was supposed to be flat, and the Church insisted that it was the center of the Universe. Long before that, the Alexandrians had had a better understanding of the order of things. Bacon knew their evidence and agreed with their opinion that the Earth was round (Davis 1992:2).

Recorded in his *Opus Majus* (1268), Bacon put forward the notion that "India" could be reached by sailing *westwards* from Spain. Uniquely, he believed that the sea *west* of Spain was so small that "(Farther) India" could be reached in only a few days if the winds were favourable (Burke 1928:311). Randles (1990:50) states that "Bacon seems to have been encouraged to allege this by the remark of Seneca, who, in his *Questiones Naturalis*, had said that the sea between Spain and India could be crossed in a 'few days, if one had a good wind to drive the ship'."¹³ However, other authors are sceptical that Bacon had

a classical source to support this geographical notion. Grant claims that “Aristotle [for example] says only that some hold that the Pillars of Hercules (Straits of Gibraltar) and India are connected, since elephants are found at both ends. Nothing is said about the sea being small or navigable” (Grant 1974:637).

Bacon considered “the remotest habitable point of Farther Spain ... the west, and the remotest point of Farther India as the east” (translated and quoted in Burke 1928:319). He claimed that this Farther India was a short sail from Farther Spain going *west* (from Spain). Going the other way, that is, *east*, starting this time at the Red Sea, it was over a year’s voyage (not including the journey east of Spain across the Mediterranean). He states

... therefore from the port on the Red Sea towards us [that is, going east] a voyage of a year and a half is required to reach India the distance of the Red Sea to the end of Farther Spain about the Atlas range is immense (translated and quoted in Burke 1928:319).

Bacon cannot have believed that the voyage west of Spain to India took a few days, while going east it took well more than a year. One can only make sense of this seeming confusion if “Father India” is substituted for the continent we call America (and the vast unknown area “about the Atlas range” identified as the Pacific Ocean). Certainly Bacon knew that this mysterious “Farther India” (that is, the American Continent) stretched down below the Tropic of Capricorn, which of course “near” India does not.¹⁴ He remarked that “in accordance with former statements ... the southern frontier of [Father] India reaches the tropic of Capricorn near the region of Patale and the neighbouring lands which are washed by a great arm of the sea flowing from the ocean which is between India and Farther Spain or Africa ...” (translated and quoted in Burke 1928:328). This “great arm of the sea” which washed the two regions

is undoubtedly the Atlantic Ocean. Bacon's primitive knowledge of the American continent must be considered extremely remarkable for a medieval European, predating by over two hundred years Columbus's first crossing of the Atlantic, or the then called Ocean Sea, in a journey which took approximately five weeks.¹⁵ The only medieval nation with the ships, the deep-sea sailing capabilities and the maritime experience to be able to discover (and to share) such knowledge in Bacon's day was China of the Sung Dynasty (see Manguin 1993:269).¹⁶

In his *Opus Majus* Bacon wrote extensively about longitude and latitude, and pondered the arbitrariness of marking 0° of longitude (Burke 1928:316–320).¹⁷ The problem of measuring longitude and latitude was also considered by the author of *De Mirabile*, where it is stated that the “greatest of all devices, ... and the greatest of all things which have been devised [is] ... that in which the heavens are described, according to longitude and latitude, with models which actually go through the diurnal movement” (translated and quoted in Davis 1992:29). Placed, as it is, under the section on optical phenomenon the device mentioned bears some comparison with the sextant,¹⁸ thought to have only been in general use in Europe from the mid-eighteenth century. Certainly, the author of *De Mirabile* considered this device to be “worth more than a kingdom to a wise man” (translated and quoted in Davis 1992:29). Bacon, whether or not he ever had access to such a wondrous device, was able to chart maps that were seemingly incredible for his time. Unfortunately the world map that accompanied the *Opus Majus* has been lost (Clegg 2003:157). It can, however, be theoretically reconstructed.

Like a modern map, it had north at the top and consisted of a series of red circles representing the positions of cities. Although this map, like all maps, was a flat, two-dimensional representation, the positions were calculated from a knowledge of latitude and longitude and projected from a three-dimensional sphere onto a two-dimensional page. If such map projections had become widely available in Bacon's time, the great *European* voyages of exploration might have begun much earlier (Clegg 2003:157–158, my italics).

Bacon's advanced system for calculating longitude was "fixing heavenly reference points above the poles and four points on the equator separated by 90°, [so] that the relative locations of other spots on the world could be calculated by noting the angle to those reference points" (Clegg 2003: 157). However, Bacon's proposed reference points would have had to have been physically achieved, which would have meant not only travelling to the equator, but to those four precise points along the equator, like segmenting an apple. These points could only have been somewhere in the north of South America, equatorial Africa, Borneo, and somewhere in the middle of the Pacific, at a time when no European had ever penetrated, or supposedly knew about, any of these regions.

In fact, Bacon's method is remarkably like the medieval Chinese solution for calculating longitude. By the early Ming dynasty the Chinese were able to do so by recording lunar eclipses and making elapsed time calculations from stationary positions. Their method for measuring time was to use gnomons enhanced with lenses inside a "camera obscura" observation chamber (Menziess 2003:370). Beijing was marked as 0° longitude and comparisons were made when those responsible for charting other longitudes returned home from their voyages (Menziess 2003:367–370).

When the astronomer returned from his voyage, he and his colleagues in Beijing compared their data. Using their time keeping device, calibrated from the gnomon, they timed the interval between the transits of the star observed in the new territory at the time of the eclipse and the star seen by the astronomers in Beijing at the same moment. The earth rotates 360° in twenty-four hours. If the elapsed time between the two transits was six hours, a quarter of the time it takes the earth to rotate, the difference in longitude between Beijing and the new territory would be a quarter of the total longitude around the world – 90° , one quarter of 360° (Menzius 2003:374).¹⁹

If “Roger Bacon’s letter” was indeed written by someone like Giovanni Carpini from inside Mongolia, someone who had heard about, or even come into direct contact with, the many technological advances of medieval China, and that this letter thereafter came into the hands of Roger Bacon, this would certainly solve Burke’s (1927:80) puzzle of the very existence of the *Opus Majus* as a work so far in advance of its own (European) age. This also solves the mystery of how medieval artists were able to acquire practical knowledge of the camera obscura to use in picture making. The Chinese origin of *De Mirabile* should also allay the discomfort certain scholars, such as Smith and Schechner feel, because they rightly consider medieval Arabian optical research to have been of little use to artists. The Chinese, however, had something artists could make use.

1.3 BACON'S DANGEROUS PROJECTIONS

Image projections had a long history in China with one of the best known Chinese sources being Shen Kua,²⁰ as has been stated. Shen Kua's *Brush Talks from Dream Brook* "is a remarkable scientific document which contains his work on mathematics, music, astronomy, calendars, cartography, geology, optics and medicine" (*MacTutor History of Mathematics Archive* 2008. Sv "Shen Kua"). *Brush Talks* may have been printed in Shen Kua's lifetime and "was first quoted in a book dated 1095" (Sivin 1995). The first biography of Shen Kua's life in English was published by Donald Holzmann in 1958 (Sivin 1995), and Needham made wide-ranging reference to *Brush Talks* in numerous of his publications. Shen Kua fully understood and observed that the *image* of an outside object, in this case a pagoda, could be projected through a hole onto a receiving support. He observed that this phenomenon occurs when light comes through a hole or small window, perfectly describing either a pinhole effect or a concave mirror projection.²¹

The image of a pagoda, passing through the hole or small window, is inverted after being 'collected.' This is the same principle as the burning mirror (translated and quoted in Needham 1962:97).

Shen Kua noted that the image is upside down, and compared this to the principle of inverted images that form in a concave mirror. He also stated that the image is not only inverted but also reversed when a pinhole is used.

When a bird flies in the air, its shadow moves along the ground in the same direction. But if its image [of the shadow] is collected (like a belt being tightened) through a small hole in a window, then the shadow moves in the direction opposite to that of the bird [outside the window] (translated and quoted in Needham 1962:97).

He considered there is a point where the image is “collected” before it is reversed, inverted and projected, and he compares this to the properties of a concave mirror, which has a focal point due to its shape. He further illustrated that the image from burning or concave mirrors are not only inverted, but are exactly in the air between the eye and the bowl.

The burning-mirror reflects objects so as to form inverted images. This is because there is a focal point in the middle (ie between the object and the mirror). It is like the pattern made by an oar moved by someone on a boat against a rowlock (as fulcrum). We can see it happening in the following example. ... [the] mirror has a concave surface, and reflects a finger to give an upright image if the object is very near, but if the finger moves farther and farther away it reaches a point where the image disappears and after that the image appears inverted. Thus the point where the image disappears is like the pinhole of the window (translated and quoted in Needham 1962:97).

Like Shen Kua, Bacon also talked about how images can be made to appear and disappear. In his *Opus Majus* he gave a more detailed description of the mirror-projection found in *De Mirabile*. He stated:

[m]irrors, moreover, can be so arranged that as many objects as we desire may be visible and all that is in the house or in the street; and any one looking at these objects will see them as they really are, and when he hastens to the places where they appear, he will find nothing. For the mirrors will be concealed in such a manner with respect to the objects that the positions of the images are in view, and the images appear in the air at the intersection of the visual rays with the catheti, and therefore those looking at them would run up to the places where they appear, and would judge that the objects are there when there is in reality nothing except an image (translated and quoted in Burke 1928:581).²²

Relevant to this discussion is Bacon’s claim that the “images appear in the air.” Reconsider Schechner’s comment that “[a]n inverted image viewed inside a shiny bowl was *not* understood by them [Witelo, Bacon, or Al-Haytham] as a *projection* in space between the eye and the bowl as we do today” (Schechner 2005:139, author’s original italics). On the contrary, Bacon clearly understood that the image was in the air “between the eye and the mirror,” and he even

attempts to give a scientific explanation for this. He states that “the images appear in the air at the intersection of the visual rays with the catheti.” Catheti are explained as lines or radii “falling perpendicular to one another; as the catheti of a right-angled triangle, that is, the two sides that include the right angle” (*Webster’s Dictionary* 2008. Sv “catheti”). Bacon supposed the phenomenon to be a result of the “visual rays,” that is, those from the eye (which Bacon believed the eye emitted), intersecting with the (reflected) rays of the objects, that is, those now redirected towards the eye (or the catheti). And again, like Shen Kua, Bacon uses the word “image” – (the “image of the pagoda” and the “image [of the bird’s shadow]”). Bacon sees “nothing except an image.”

In the medieval era writers did not use a blanket term to describe the “camera obscura,” the term first being used by Johannes Kepler in 1604 (Naughton 2003), which is a further reason why some modern writers perhaps overlook references to “dark rooms” in medieval writings. In trying to understand the working of the eye, however, Bacon quite clearly makes a comparison with a “camera obscura” in the following passage, for example.

The coats and humors [of the eye], according to Alhazen, have their admirable qualities, from which follow the benefits of vision, as he himself shows. ... the cornea ... is, moreover, transparent, so that the impressions [species] of light and colour may pass through it, as was verified before The uvea is usually black, in order that the humour albugineus [aqueous humour] and the glacialis [lens] may be obscured, so that feeble impressions of light and colour may appear in it, since feeble light is very apparent in dark places, and is concealed in places full of light (Bacon translated and quoted in Burke 1928:444).

Bacon’s comment here seems contrary to common sense, in that to see the feeble light everything else must be absolutely dark, in other words, he is

describing light coming through a pinhole into a dark room, or “camera obscura.”

Bacon did not limit his interest to mirrors, as he also experimented with, and wrote about, lenses. This special interest in perspectiva, the fledgling science of optics, was undoubtedly re-enforced by Bacon’s great admiration for Grosseteste (Goldstone & Goldstone 2005:69). After 1250, Bacon also used a Latin translation of the work of al-Haytham as a theoretical source (Clegg 2003:61). Regarding lenses Bacon expanded on the ideas put forward in *De Mirabile*. In the *Opus Majus* he very clearly describes telescopes and microscopes.

The wonders of refracted vision are still greater; for it is easily shown by the rules stated above that very large objects can be made to appear very small, and the reverse, and very distant objects will seem very close at hand, and conversely. For we can so shape transparent bodies, and arrange them in such a way with respect to our sight and objects of vision, that the rays will be refracted and bent in any direction we desire, and under any angle we wish we shall see the object near or at a distance. ... So also we might cause the sun, moon and stars in appearance to descend here below ...” (translated and quoted in Burke 1928:582).

The “transparent bodies” which Bacon is referring to are, of course, lenses, arranged in multiples in order to demonstrate telescopic and microscopic effects. Needham points out that the Chinese knew about the action of the telescope long before it was considered in the West, the knowledge declining under the Ming dynasty (Needham 1962:117). Bacon could have sourced a number of lenses from China to assist him in his practical experimentation.

By the tenth century [the Chinese] ... had fashioned lenses of various shapes, and knew that while some magnified images others could give a reduced image, ... Chinese lenses were made from naturally occurring rock crystals, though it seems likely that glass was also used, ... , for China had a glass industry as early as the sixth century (Ronan 1983:171).

With his somewhat unusual knowledge of so many fields previously fallow in European thinking, Roger Bacon has sometimes been

... dubbed *Doctor Mirabilis* (the miraculous doctor)... an expert in mathematics, astronomy, optics, alchemy, languages and homeopathic medicine. He had described the workings of the telescope and microscope four hundred years before Newton. He believed that the earth was spherical and that one could sail around it, an argument that was purported to have inspired Columbus two hundred years later. He believed that light moved at a distinct speed at a time when it was assumed that the movement was instantaneous. He questioned Galen, the great Roman anatomist and physician, and theorized about illness, disease, and the human body centuries before anatomy and medicine poked their heads into the modern age. He has sometimes been credited with inventing eyeglasses. He wrote of flying machines, motorized ships, horseless carriages, and submarines. He was the first man in Europe to describe in detail the formula for making gunpowder (Goldstone & Goldstone 2005:9–10).

And yet around 1257 it is said he “suddenly, ... threw up his entire way of life to become a Franciscan friar” (Clegg 2003: 51) and seemingly surrendered all his worldly possessions to enter a cloistered life of hardship and suffering. Shortly after supposedly “joining” the Franciscan order he was transferred from Oxford to Paris, and kept in a small cell (Goldstone & Goldstone 2005:118). He would later write that his “superiors and brothers, disciplining me with hunger, kept me under close guard and would not permit anyone to come to me, fearing that my writings would be divulged to others [rather] than to the chief pontiff and themselves” (quoted in Goldstone & Goldstone 2005:118).

This treatment – the enforced fasting, the poverty, the menial labor, the begging – took its toll on a man who was already in his mid-forties. They treated him with “unspeakable violence,” he wrote, and as a result his health broke down ... (Goldstone & Goldstone 2005:118).

It seems unlikely, from this evidence, that Bacon was a willing participant to what can only be called an incarceration. Many years later he was to malign the

Franciscan order as if he had never been a member (Goldstone & Goldstone 2005:164).

Nevertheless, as a university professor Bacon would have been required to be not only a Christian but also a member of the minor clergy. Oxford and Paris, as with all European universities of those times, were under the auspices and control of the Church. “Scholasticism was the method that would be used in every university, the rule book in the battle of dogma against science, the system by which Roger Bacon learned and later taught, which molded his philosophy of science and provided its greatest impediment” (Goldstone & Goldstone 2005:39). By leaving Paris in 1247, of his own volition, and taking on a life of independent study and research, Bacon put himself directly into the firing line of the Inquisition. As Bacon “pressed forward into new areas of [scientific] investigation he was in danger of gaining a reputation as a dabbler in the black arts” (Clegg 2003:52). Knowledge gained outside of the Church’s orbit was knowledge which could not be controlled.

The papal Inquisition was formally appropriated under Pope Gregory IX in 1231 with the constitution *Excommunicamus* (*Encyclopedia Britannica* 2005. Sv “Inquisition”). At the Council of Lérida in 1237 the Inquisition was confined to the Dominicans and the Franciscans (*Catholic Encyclopedia* (VIII) 1910. Sv “Inquisition”). With new powers those people that the Church considered “heretics,” like Bacon, could be apprehended and tried. Torture was censured in a bull, *ad extirpanda*, issued by Pope Innocent IV in 1252 (*Encyclopedia Britannica* 2005. Sv “Inquisition”).

The principle of toleration was unknown, or at best only here and there a voice was raised against the death penalty [burning at the stake]. ... No

distinction was made between the man and the error. The popes were chiefly responsible for the policy which acted upon this view. ... From the latter part of the twelfth century, councils advocated the death penalty, popes insisted on it, and Thomas Aquinas elaborately defended it. Heresy ... was a crime the Church could not tolerate (Schaff 1979:86).

The Church's institutionalised witch-hunt against free thinkers and radicals could not have been unknown to Bacon and it seems highly implausible that he would willingly surrender himself to custodians of the Inquisition, even if he had run out of family funding as many modern authors suggest (Clegg 2003:52).

As it was he languished for six years in his "friar's cell" in Paris, until sometime in 1263 he managed to get a secret message to a man he admired and thought might help him (Goldstone & Goldstone 2005:133). Cardinal Guy le Foulques was from the French region of Languedoc and had lived through the Crusade against the Cathars in that region (Clegg 2003:90). He was a lawyer with an imposing reputation, who entered the Church after his wife died (Clegg 2003:91). Bacon received a positive reply from Foulques, who did, indeed, show interest in his work, but was under the assumption that Bacon had a book to send him, which was untrue (Clegg 2003:96). In 1265 Bacon had a bit of good luck. Cardinal le Foulques, probably himself somewhat astonished by the circumstances, was called to Viterbo, near Rome, having been elected Pope Clement IV (Goldstone & Goldstone 2005:134). Later, in 1266, Bacon managed to get another message to le Foulques, now pope, this time in the hands of the English emissary Sir William Bonecor, who may have been a family friend (Goldstone & Goldstone 2005:135).

Finally, on 22 June 1266, (nearly ten years after Bacon's first incarceration) Pope Clement IV issued an instruction to Roger Bacon. Bacon

was to “send him ‘his writings and remedies for current conditions,’ but to use as much secrecy as possible and to carry out his action ‘notwithstanding any prohibitions of his Order’” (Clegg 2003:96). Bacon was free to leave the confines of the Franciscan order in Paris and to return to his work. But his hardships were not over. The Franciscans provided him with no compensation and family funds were, seemingly, no longer available. He tried to use the pope’s name to beg assistance from well-known merchants and financiers, but they also left him high and dry (Clegg 2003:98). In the end he managed to scrounge £60 (about £300 thousand sterling) from friends, and he set about writing (probably with the help of scribes) his philosophies, his experiments and his knowledge into his *Opus Majus*, which ran to 840 large folios (Clegg 2003:98). The section on *Perspectiva*, or Optics, in the *Opus Majus*, was to prove crucial to the introduction of individualism into Italian painting.

1.4 TRACING THE PROJECTED IMAGE TO ITALY

Bacon added further works to his *Opus Majus* (the *Opus Minus* and *De Multipliatione Specierum*) and entrusted them to his prize-winning pupil, a boy called John, who set off for Viterbo in 1268 (Goldstone & Goldstone 2005:152). It is unclear whether Clement IV ever got to see Bacon’s work as he died in November of that year. The death of this sympathetic pope was certainly further bad news for Roger Bacon and his career. “During the interregnum following the death of Clement, the struggle between the seculars and the Orders had broken out afresh, and rivalry between the two Orders [Franciscan and

Dominican] made the confusion worse” (Easton 1952:189). That the *Opus Majus* reached Viterbo cannot be doubted, as Witelo, then living in Viterbo, left behind in his possessions a dated and annotated copy, which is now in the Vatican library (Goldstone & Goldstone 2005:159). Witelo also immediately set about systematically copying from Bacon’s work. Around 1270 Witelo released *Perspectiva*, his book on optics, and thereby ultimately took the early scholarly glory for a lot of Bacon’s ideas.²³

What happened to Roger Bacon after 1270 is a bit hazy. He might, at some time, have been allowed to return to Oxford (Clegg 2003:112). In the years following Clement’s death he completed the first section of an encyclopedia, *Compendia Studii Philosophii*, which he addressed to Pope Gregory X (elected 1274). “In addition to detailed sections on optics, language, and scriptural inaccuracy, the *Compendia* ... included long diatribes in which Bacon vented his fury at the mendicants [Franciscans and Dominicans], the secular masters, the arts faculty, and what he saw as a theology run amok” (Goldstone & Goldstone 2005:164). It was as if Bacon, now around sixty years of age, was writing his own death warrant. A Franciscan record dating from 1370, titled *Chronicle of the Twenty-Four Generals* (of the Order of Friars Minor), states the following:

This Minister General brother Jerome by the advice of many friars condemned and reprobated the teaching of Friar Roger Bacon of England, master of sacred theology, as containing some suspected novelties, on account of which the same Roger was condemned to prison, – commanding all the friars that none of them should maintain this teaching but should avoid it as reprobated by the Order. On this matter he wrote also to Pope Nicholas (III) in order that by his authority that dangerous teaching might be completely suppressed (translated and quoted in Goldstone & Goldstone 2005:170, authors’ original italics).

It is considered that *this* Roger Bacon of England was indeed *the* Roger Bacon, and that he was (re-)imprisoned sometime around 1278. It seems that the Catholic Church sanctioned optical researches only if the said researches were strictly under its control.

Around 1290 it appears that Bacon was freed, probably under the general clemency of a new Franciscan leader, Raymond of Gaufredi, after Jerome became Pope Nicholas IV in 1288 (Goldstone & Goldstone 2005:171). Bacon's last literary effort was "a sad, confused, and tired work, written by an old man" titled the *Compendium of Theology* (Goldstone & Goldstone 2005:171). It is reported that he died in 1292 at an advanced age and was buried on 11 June, the Feast of Saint Barnabas, at Grey Friars in Oxford, England (Clegg 2003:162). As has been stated, in 1492 Christopher Columbus set sail for the "Indies" based on information which came directly from Roger Bacon, a fact Columbus was unaware of. By then, the reputation of Roger Bacon was non-existent except among a few hardy followers like the later John Dee.

As for China, due to its own historical course, knowledge of its maritime might passed into legend.

At its height in the early fifteenth century, the great Ming navy consisted of 3,500 vessels: 2,700 of them were warships at the dozens of coastal patrol stations up and down the coast, 400 were warships based at Xinjiangkou near Nanjing, and 400 were armed transport vessels for grain. In Zhejiang province alone, the fleet consisted of over 700 junks. But by 1440 the number of Zhejiang ships had been reduced to less than half that. By the middle of the fifteenth century, the provincial fleets were at a fraction of their former strength. By 1500 it was a capital offense to build boats of more than two masts, and in 1525 an imperial edict authorized coastal authorities to destroy all oceangoing ships and to arrest the merchants who sailed them. By 1551, at the height of *wako* piracy on the southeast China coast, it was a crime to go to sea in a multimasted ship, even for purpose of trade. In less than a hundred years, the greatest navy

the world had ever known ordered itself into extinction (Levathes 1994:174–175).

Nevertheless it cannot be denied that, for many centuries, China ruled the seas, and might well have conquered all the oceans long before Columbus thought of sailing west from Spain in search of “Farther India.”

With the death of Pope Clement IV in 1268 information about the camera obscura and how to make projected images remained in the hands of the Viterbo papacy, and it was likely the Church who then commissioned the first paintings seen to apply what René Arb, already in 1959, called “nascent realism” in Italian art (Arb 1959:192). If indeed Bacon acquired the *De Mirabile* letter in Paris from a source in China, then knowledge of image projections travelled from Beijing to Karakorum, then to Paris, and finally to Italy. Bacon thereafter spent as many as ten years in England experimenting with mirrors and lenses. He was finally able to write up this knowledge of projected images in his *Opus Majus*, which he sent to Italy in the hands of young John. Finally the knowledge, now in the possession of the Dominicans, appears to have been acquired by the Florentine artist, Cimabue.

In finding a point of departure for the earliest optically-enhanced paintings in Italian art it is necessary to situate the artists within the available scientific milieu, and also to place optical research in the vicinity of the artists. However, as the dating of medieval artworks is mostly difficult and imprecise, it is impossible to claim any work as definitively “the first.”²⁴ Nevertheless, what is crucial is that Cimabue was in Rome around the time that Roger Bacon’s *Opus Majus* was fast becoming a consulted text in scholarly circles. It is not clear when and exactly why Cimabue went to Rome, but documents locate him there

in 1272 (Tomei 1997:48). Using Roger Bacon's description, projected images became something to copy or, at the very least, to emulate. The scope of this study starts, therefore, around 1270, an important milestone in the history of optics in Western Europe as well as in Italian painting. It begins with a commission executed most likely by the Florentine artist Cimabue, for a Dominican church in Arezzo.

Notes to this section

¹ There is also a mention of a printed Parisian edition as early as 1542 (Davis 1992:51). Dee was an avid collector of ancient books and manuscripts, and in total his library consisted eventually of 4 000 volumes, 3 600 more than Cambridge University (Goldstone & Goldstone 2005: 180). He owned works of Aristotle, Avicenna, Albertus Magnus, Thomas Aquinas, Robert Grosseteste, Euclid, Ptolemy and St Augustine, amongst others (Goldstone & Goldstone 2005:180). He eventually also had in his collection thirty-seven of the hundred and seven Bacon works then known to be in existence, many of them originals (Goldstone & Goldstone 2005:180).

² This passage is also quoted in Hockney (2001:206, under *The Textual Evidence*:201–225). However, Hockney fails to connect this passage to his 1420 theory.

³ The author's allusion to classical sources is seen throughout *De Mirabile*. However, he links the inventions (he has seen) to ideas heard of from classical sources, sometimes in ways that are unconvincing, as is shown later in Chapter One.

⁴ In mentioning Al-Haytham, Smith seems to be also unaware that al-Haytham used the camera obscura to view images of the moon (Charles Falco ???).

⁵ Kenneth Rexroth reviewed Joseph Needham's *Science and Civilization in China* when it first started to be published (1956), detailing his own excitement of the mammoth scope and importance of Needham's work. "Some of Needham's information is intrinsically exciting – for instance, the story of mammoth Chinese ships cruising the east coast of Africa and turning the Cape of Good Hope and venturing into the Atlantic before ever Vasco da Gama came the other way." It was over forty years later that any one took up this challenge to received occidental history, and even then the challenger wasn't even an historian, but a retired submarine pilot with an interest in old maps (Gavin Menzies).

⁶ I found a website funded by a group calling themselves the "British born Chinese," which makes the remarkable claim that by the time of the Mongol rule, experimentation had been carried out in China for a variety of novel and unimaginably advanced concepts, including flying machines, the submarine, telescopes and the torpedo, all later considered too crude and rejected by the Ming Chinese in the fourteenth century (www.britishbornchinese.org.uk/pages/culture/history/mongols.html). Such novelties, except the torpedo, are also mentioned in *De Mirabile*.

⁷ Galleys are propelled by oar. "The earliest galley specification comes from an order of Charles I of Sicily, in 1275 AD (in both Bass & Pryor)... Overall length 39.30 m, keel length 28.03 m, depth 2.08 m. Hull width 3.67 m. ... Overall deadweight tonnage approximately 80 metric tons. This type of vessel had two, later three, men on a bench but each working his own oar" (Wikipedia [Online Dictionary]. Sv. "Galley"). Galleys were not, however, suited to deep water sailing.

⁸ "Long before European craft sported more than one mast, the junk bore several. ... Adoption of bulkheads and the fore and aft rig mark the junk, already old practice when Marco Polo returned to Venice in the last decade of the thirteenth century, as a highly technologically advanced sailing ship, incomparably finer than anything produced in Europe. That the junk bore a high stern and a bow platform, giving it a rather clumsy appearance to western eyes, belies the effectiveness of hull and rig to fulfil its function. But there was yet another quality which, when it finally appeared in European ship-design, was to have a revolutionary effect. And this additional feature was the stern-hung rudder. ... Whether the concept of the rudder was the result of returning [European] traveller's tales to advantage, the separate realisation of the idea in the west, or a simultaneous invention, will never be known" (Woodman 1997:39).

⁹ By the Yüan dynasty the Chinese had sails that reefed in a concertina fashion like a Venetian blind, making them more stable when riding anchor. See Gavin Menzies (2003) for information on how recent finds in China have started to corroborate early stories about the size and sophistication of medieval and early Renaissance Chinese junks. Joseph Needham, followed by Gavin Menzies and others, believed that Chinese junks had sailed round the tip of Africa and on into the Atlantic long before Vasco da Gama came the other way (www.bopsecrets.org/rexroth/essays/needham.htm). But how long before da Gama? This question is still to be satisfactorily answered.

¹⁰ It also seems very odd that Bacon, himself then also a teacher of Aristotelian philosophy, should send a formula for gunpowder to a bishop.

¹¹ Even if one considers, like Davis does, that the amount quoted is actually in Parisian pounds, which was worth about one third of English pounds, the amount is still an exorbitant £3.5 million sterling in today's currency.

¹² Yet, if we accept his authorship of *De Mirabile*, then we must also accept that, by 1250, he had also somehow seen fast-moving "great ships and sea-going vessels," undoubtedly Chinese junks that could only have been witnessed by a traveller to the Far East.

¹³ Seneca could also have been referring to a journey *east* of Spain, not *west*. If an ancient Suez canal did exist, as reported by modern Israeli geologists in *Time Magazine* in 1975, then maritime traffic would have had direct access to the Red Sea from the Mediterranean. "While studying aerial photographs of the Nile Delta after their country's 1967 conquest of the Sinai, Israeli geologists noticed soil markings that were clearly vestiges of two dried-up waterways. One was quickly identified as a silted offshoot of the Nile River called the Pelusiac branch (after the ancient city of Pelusium at its mouth). The nature of the other waterway baffled the geologists until they visited the area and found man-made embankments. With that, they realized that these old mounds marked the route of a remarkable ancient canal that predated the Suez Canal by as many as 4,000 years" (*Time Magazine* Monday 20 October, 1975).

¹⁴ What Bacon was unsure of however, was just how "joined up" the "near" India of more common knowledge was with what he called "Farther India" (in other words, how big is the sea we now call the Pacific Ocean).

¹⁵ Bacon, a medieval English monk, would have taken quite a few days just to cross the English Channel in a 20 m long boat.

¹⁶ This is an area of early maritime history that needs to be more thoroughly researched, as my reinterpretation of Bacon's *Opus Majus* shows a medieval knowledge of world geography that is remarkable. Menzies (2003) suppositions for the 1420 "discovery" of the "world" by China is probably too late, as the Chinese were probably sailing the deep waters of the Atlantic and the Pacific at least two centuries before this.

¹⁷ There is no indisputable mid point in longitude, such as the equator exists for latitude.

¹⁸ "A **sextant** is a measuring instrument generally used to measure the angle of elevation of a celestial object above the horizon. Making this measurement is known as *sighting* the object, *shooting* the object, or *taking a sight*. The angle, and the time when it was measured, can be used to calculate a position line on a nautical or aeronautical chart. A common use of the sextant is to sight the sun at noon to find one's latitude. ... Held horizontally, the sextant can be used to measure the angle between any two objects, such as between two lighthouses, which will, similarly, allow for calculation of a line of position on a chart (Wikipedia [Online free encyclopedia]. Sv. "Sextant"). The sextant includes a telescope and a number of mirrors in its design.

¹⁹ The idea to use astronomical events to calculate longitude was mentioned by Ptolemy (c.85–c.165) in the early Christian era. He advocated the method of Hipparchos (c.190–c.120 BCE), which was to "mark the precise moment when a heavenly event occurs [for example, a lunar eclipse], one which may be seen simultaneously across the globe" (Menzies 2003:368). However, it is thought that this method only became generally known in Europe around 1415, when Ptolemy's *Geographia* was taken to Venice by two Byzantines escaping the Ottomans (Menzies 2003:368). Further, Ptolemy's method required a diligent and precise way of measuring of time, that is, in a period when the West had no clocks like the Chinese gnomons.

²⁰ David Hockney, in his proposal for the use of optics as early as 1420, cites the writings of the Chinese master Shen Kua in *Secret Knowledge* (Hockney 2001:205–206). Although he presents a passage from Shen Kua in an appendix, he fails to demonstrate how such information came into the hands of the artists he considers to be the first users of optics. Consider also that there is a long gap, and a large geographical distance, between the Chinese Shen Kua of the eleventh century and the Flemish Jan van Eyck of the early fifteenth century.

²¹ To observe the phenomenon of an image projection, it is not that necessary to have the room particularly dark. Hold up a simple magnifying glass in such a way that the scene outside the window (on a bright day) can be projected onto a wall or a piece of paper inside the room. The image will be quite clear, and is particularly startling if something outside the window is

moving, say for example washing flapping in the breeze. The image will, of course, be upside down and reversed.

²² Bacon's mention of objects that are "in the house or in the street" is reminiscent of a later sixteenth-century description of a camera obscura by Girolamo Cardano.

²³ As an example of Witelo's blatant plagiarism, and failure to acknowledge his sources compare the following extracts:

Al-Haytham: "And we would say in the first place that sight occurs only by means of the glacial humor, whether sight takes place through forms coming from the visible object to the eye or in some other way. ... for if injury should befall the glacial humor, the other tunics remaining sound, sight is destroyed; if the other tunics should be corrupted, their transparency and the health of the glacial humor being retained, sight is not destroyed." Roger Bacon: "The anterior glacial humor has many properties. The first and principal of these is that the visual power resides only in it, according to Alhazen and others. For if the glacial humor should be injured, the others being preserved, sight is destroyed; and if the glacial humor is preserved, injury befalling the others (provided their transparency remains), sight is not destroyed ..." and Witelo: "And so it is evident from these things that the glacial humor is properly the organ of the visual power, for the transparency of only this humor is receptive of the forms of visible objects, ... And if any tunic or humor whatever, saving the glacial humor, should be injured, the eye ... is healed and sight is restored. However, when the glacial humor itself has been damaged, all of the sight is destroyed ..." (Lindberg 1974:400). Witelo, unlike Bacon, quotes no source, giving the impression that the knowledge is his.

²⁴ [Giunta Pisano ???](#)

CHAPTER 2

Cimabue, individualism and the optical portrait

2.1 THE NOBLE PAINTER OF FLORENCE

The first application of optics in medieval Italian painting appears to be linked to two main centres, Florence and Siena, Tuscan city states who were often at war. The Florentines and Sieneese fought two major battles in the 1260s. At the Battle of Montaperti in 1260 the Sieneese trounced the Florentines, leaving 10,000 dead on the battlefield, but in 1269 the Florentines had their revenge at the Battle of Colle Val d'Elsa, and Sieneese power began to decline in Tuscany (Cole 1980:xi). Siena was without a manufacturing base, and relied on trade and banking, and its strategic position on the Via Francigena, the main pilgrim road between Rome and the Lombard north (Catoni 2000:8). On the other hand, there was a steady rise of Florentine political and economic dominance in Tuscany after 1269, as Florence also became increasingly important on the Italian cultural stage (Cole 1980:xi).

It was the triumphant Florentines, therefore, who wrote the art history of Tuscany from a Florentine point of view. Because of this perspective, the Florentines Cimabue and Giotto have been continually praised through the centuries for the foundations of what could be called Italian naturalism. The Sieneese Duccio was marginalised until very recently, as for example in the way the Rucellai *Madonna* was consistently attributed to Cimabue, even into the

twentieth century (Maginnis 1994:150). It was early in the fourteenth century that the Florentine poet Dante Alighieri (1265–1321) first immortalised his fellow Florentines.

In painting Cimabue thought that he
Should hold the field, now Giotto has the cry,
So that the other's fame is growing dim
(Dante, *The Divine Comedy: Purgatory*, Canto XI, quoted in Cole 1980:11).

Over two centuries later Florentine biographer Giorgio Vasari became the new standard bearer of Florentine painting, and he too cited Cimabue as the founder of “modern” Italian painting and a precursor to Giotto.

Through the endless floods of evils that dragged down and drowned wretched Italy, not only were ruined those things that could be called buildings, what mattered still more, quite extinguished were all craftsmen, when, by the will of God, there was born in the city of Florence, in the year 1240, in order to give the first lights to the art of painting, Giovanni surnamed Cimabue, of the Cimabue family, noble at that time (translated and quoted in Maginnis 1994:147).¹

Vasari tries to explain Cimabue’s expertise. He claims that Cimabue, who was particularly intelligent so that his father wanted him to “train in letters,” nevertheless did not feel inclined towards studying (quoted in Maginnis 1994:147). However, Vasari’s supposition that Cimabue instead spent his “entire day painting in his books or on other sheets men, horses, buildings and various fancies, driven by a natural inclination that he thought would go to waste if not exercised” (translated and quoted in Maginnis 1994:147), ignores the fact that the first paper mill was only set up in Italy in 1270 (Hallam 1853:458) and parchment was expensive.² There is no remaining physical evidence, such as preserved parchment books or sheets, proving that Cimabue was a prodigious drawer from life, or that such practices existed at that time.

A further Vasarian explanation for Cimabue's unprecedented style was to credit the arrival of certain "Greek" masters in Florence.

It happened in those days certain Greek painters came to Florence, having been summoned by those who governed the city, for no other purpose than that of introducing there the art of painting, which in Tuscany long had been lost. ... And Cimabue, having begun to take the first steps in this art that pleased him, often fled from school and spent the entire day watching those masters work (translated and quoted in Maginnis 1994:147).³

These "Greek painters" were from the near East, specialists in the *Byzantine* style, a model which Cimabue increasingly moved away from, perhaps because rising humanist sentiments in general made different demands on him as an artist. Vasari makes the enigmatic claim that it was "nature" which aided Cimabue, who "with continual practice, ... in drawing and colouring ... surpassed the masters who had taught him [*la natura lo aiutò talmente ch'e' passo di gran lungo di disegno e di colorito e' maestri che gl'insegnavano*]" (quoted in Maginnis 1994:147; Italian quoted in Maginnis 1994:162). Perhaps this "natural assistance" Cimabue received came directly from projected images, through the introduction around 1270 of optical technology into an elite stratum of Italian cultural and scientific life. According to Vasari, Cimabue brought this "something new ... [to Italian painting], for the bearing of the heads and folds of the drapery, ... [were better] than what those Greek masters had done up until then" (translated and quoted in Maginnis 1994:148). He sees in this the "features of the modern" (quoted in Maginnis 1994:148).

Vasari also claims that Cimabue worked with plenty of light, in the outdoors, but in secret.

And it is said that while Cimabue painted that panel in certain gardens [*certi orti*] close to the Porta S. Piero, for no other reason than to have

good light and good air and to flee the frequent company of men ...” (quoted in Maginnis 1994:148; Italian quoted in Maginnis 1994:162).⁴

The exact translation of “*orti*,” however, is “kitchen-gardens.” It is hard to envisage why an artist using traditional methods would want to work outside in hot sunlight in a kitchen-garden. Yet, if one considers that to create a projected image requires the right amount of light, at the right angle (fig 2), then such a setup becomes highly plausible. A walled kitchen-garden would make an ideal setting for a camera obscura, and also provide privacy.

Vasari ends his biography of Cimabue quoting the contemporary reaction to the Rucellai *Madonna* (which Cimabue, in any case, was never commissioned to paint).

Because it [the Rucellai *Madonna*] had not yet been seen by anyone, it being shown to the king, there immediately came together all the men and all the women of Florence with great rejoicing and in the largest crowd on earth (translated and quoted in Maginnis 1994:149).⁵

Vasari’s biography was probably based a little on legend, a little on commentaries such as the *Ottimo Commento* (to Dante’s *Divine Comedy*) by Villani (1381–1382), and on some guesswork (Chiellini 1988:1). Chiellini (1988:1) states that as late as the early twentieth century certain scholars challenged the very existence of Cimabue. Even until recently the artist’s name was not well understood. Vasari thought that “Cimabui” was a family name with noble connections, but it was, in fact, a nickname likely related to the verb “*cimare*,” to prune, or to cut back (Chiellini 1988:3). The *Ottimo Commento* of Villani claims that Cimabue was an arrogant and disdainful person, with a sharp character (Chiellini 1988:3).

The most important, and earliest, documentary evidence of Cimabue (Giovanni de Pepo), places him in Rome in 1272 (Chiellini 1988:1–2), shortly after Witelo published *Perspectiva*, his book on optics. It is my conjecture that someone at this time, connected to the Viterbo papacy, introduced Cimabue to the phenomenon of image projections outlined in Witelo's book and plagiarised from Roger Bacon, so that it is no coincidence that one of the first works to exhibit traces of copying from an image projection is Cimabue's San Domenico Arezzo *Crucifix* (c.1272–1275, plate 1).

Unfortunately, not one document about this extraordinary *Crucifix* exists, not even indirect mention throughout the past centuries. It is therefore necessary to go back to what was cited by Cavalcaselle in 1875, whose attribution to Margaritone was simply his referral to the local tradition of ascribing the most ancient medieval works of unknown origin to the mythical "*Margaritone*": a term coined by Vasari, Subsequently, a more critical observation was made by Siren (1922) who attributed the cross to Coppo di Marcovaldo. Vitzdum and Volbach (1924) have esteemed it to be one of the most significant works among those derived from Giunta Pisano. The decisive attribution to the great master [Cimabue] was upheld for the first time by Pietro Toesca (1927): an attribution that has been widely accepted ... (Maetzke 2001:27).

2.2 THE PAINTED WOODEN CRUCIFIX

2.2.1 A new fidelity to nature

Panel painting was introduced into Italy in the twelfth and thirteenth centuries, firstly with wooden crucifixes, and then later with wooden altarpieces of the Madonna (Eimerl 1967:16). Cimabue would have had examples of wooden crucifixes to study in nearby Pisa, such as Pisa *Crucifix No. 15* (late twelfth

century, plate 2) and Pisa *Crucifix No. 20* (early thirteenth century, plate 3). These large and graceful Italo-Byzantine representations of Christ crucified are forerunners of the depiction of Christ on the San Domenico Arezzo *Crucifix*. The Pisa crucifixes are less naturalistic than the San Domenico Arezzo *Crucifix*, but one should be careful not to dismiss them, out of hand, as unrealistic. Christ stands upright in Pisa *Crucifix No 15* and is depicted without pain or suffering, very much alive, triumphant over death as *Christus Triumphans* (Eimerl 1967:18). The figure is represented by a shorthand method, in other words, it is linear, briefly descriptive and without particular modelling of form. Nevertheless, the artist has paid attention to the human figure in a fairly specific way so it cannot be stated that he never studied a male torso. The proportions are inaccurate, with short arms, but the artist shows some knowledge of structure, with the ribcage and belly clearly demarcated. The pectoral muscles are prominently portrayed and the appendages are articulated with knees and ankles, and elbows and wrists. The face is somewhat rudimentary, with a singularly linear depiction of eyes, eyebrows, nose and mouth, above which is marked a small moustache. The eyeballs float in symmetrical almond-shaped eyeballs, but there is a crease below the eye hinting to an underlying rounded structure. Importantly though, this depiction of Christ is more universalised, and does not concern itself to portray a specific individual in time and/or space.

The figure of Christ on Pisa *Crucifix No 20*, painted perhaps half a century later, is similar in execution to Pisa *Crucifix No 15*, although the figure is now somewhat slumped forward, with the knees and elbows slightly bent,

and the head rolling to one side, showing Christ suffering. Although the face has been executed with the eyes now closed, it remains nevertheless closely comparable in style to *Pisa Crucifix No 15*, with the hair a solid mass, highlighted with strands that poke over the shoulders. At the very apex of *Pisa Crucifix No 20*, a miniature figure of Christ triumphant is illustrated on a roundel, with six angels on a rectangular shaped board below. As with the *Pisa Crucifix No 15*, there are numerous illustrative scenes of the passion.

The *San Domenico Arezzo Crucifix*, considered to be one of Cimabue's earliest extant works, is dated to around fifty years later than *Pisa Crucifix No 20*. It was placed above the saint's altar from the inception of the Dominican church in Arezzo, where it is still found today (Chiellini 1998:10). Having received this commission sometime around 1270, Cimabue would have been required to follow certain traditions, copying certain poses like those of Christ on the *Pisa crucifixes* already mentioned. These poses were entrenched in the formalised style of a mainly Byzantine tradition (Chiellini 1988:6). This Near Eastern influence had arrived in Italy, carried back from various Crusades, for example, the sacking of Constantinople on 13 April 1204, when hordes of booty was taken to Italy, including religious artworks and illuminated manuscripts (Eimerl 1967:38).⁶

The depiction of Christ with a slight sway to the body and the head falling onto the chest, with the eyes closed as a symbol of death, as seen in the *San Domenico Arezzo Crucifix*, was rooted in such early models as the Byzantine-style mosaic crucifixion scene in the narthex of the Monastery Church of Hosios Lukas, near Delphi in Greece (plate 4). Although it is

unlikely that Cimabue got to see this mosaic in person, he would have had access to similar descriptions in model books and manuscripts, for example, the *Universal Male* (c.1200, fig 3) illustrated in later copies of the *Liber Divinorum Operum* (1178) by Hildegard of Bingen (1098–1179). Details from the Hosios Lukas crucifix, such as the basic fold of the loin cloth and the graphic description of the bare abdominals, are echoed by Cimabue in the San Domenico Arezzo *Crucifix*. Such religious works were very much restricted under the pronouncement of the Second Nicean Council (787) which decreed: “The composition of figures is not the invention of the painters but the law and tradition of the Church, and this purpose and tradition is not the part of the painter (for his is only the art) but is due to the ordination and the disposition of our Fathers” (Eimerl 1967:36). The Chartres Chapter Meeting (1298) further advised against “strange digressions in the works commissioned for monasteries: *nullae curiositates notabiles fiant*” (Chiellini 1988:8). This meant that although an artist executed the work, the final results were to look like what the Church fathers expected.

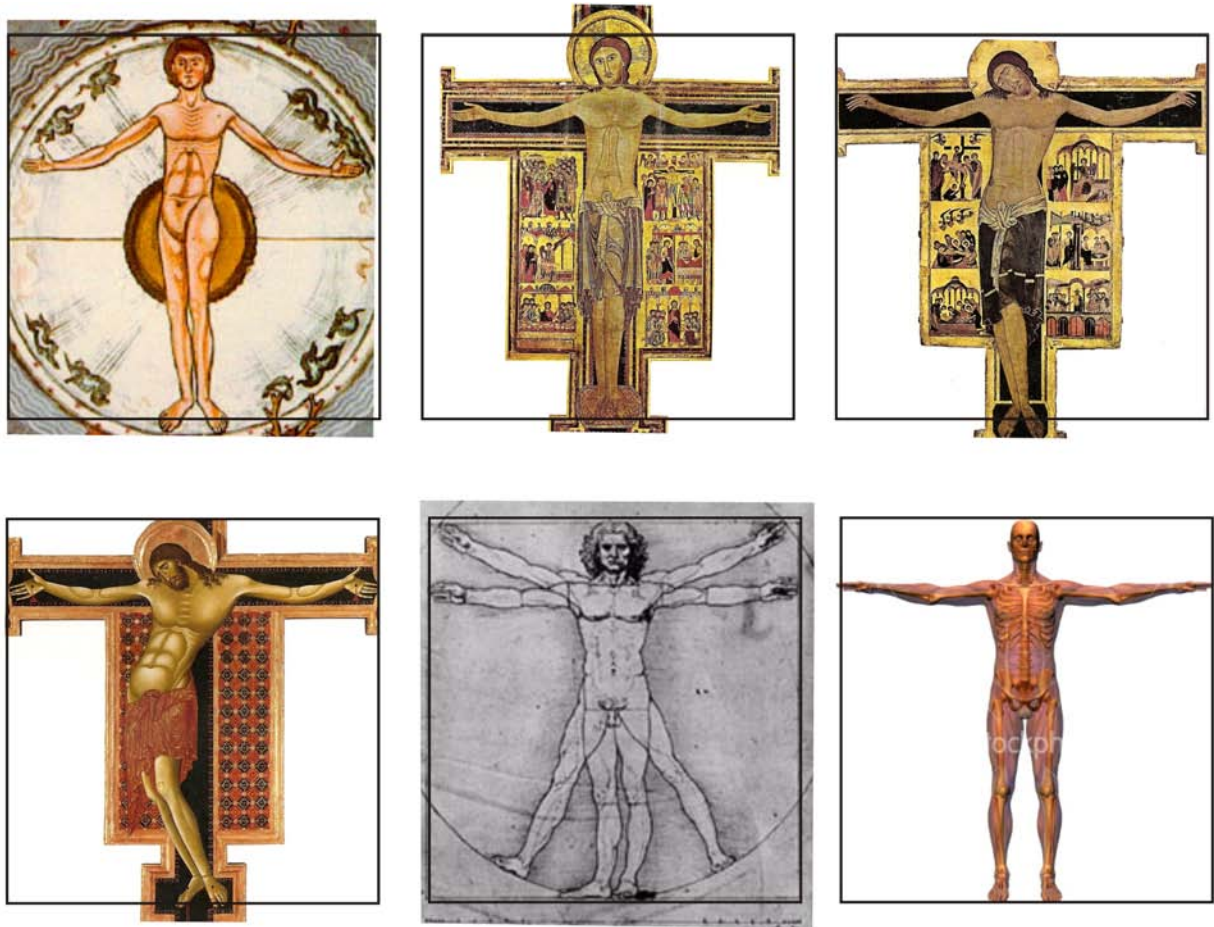
Chiellini notes the likenesses between earlier crucifixes and the San Domenico Arezzo *Crucifix*, the style of which she says stayed “the same way for a very long period of time” (Chiellini 1988:11). She gives her assumption for this.

This is because the symbolism of the subject does not allow for free interpretations, as is obvious also from the fact that Christ’s body is always portrayed according to very strict principles of proportion, which, particularly for Dominican theologians, conveyed mystical values as well. The figure is also placed within a square plan according to the system that Vitruvius used: a man portrayed with outstretched arms will measure the same in height as he does in width. St Hildegard of Bingen further explained that this equidistance represents the perfect balance

resulting from moral beauty, as well as being a reflection of cosmic harmony: *quemadmodum etiam firmamentum aequalem longitudinem et latitudinem habet* (Chiellini 1988:11–12).

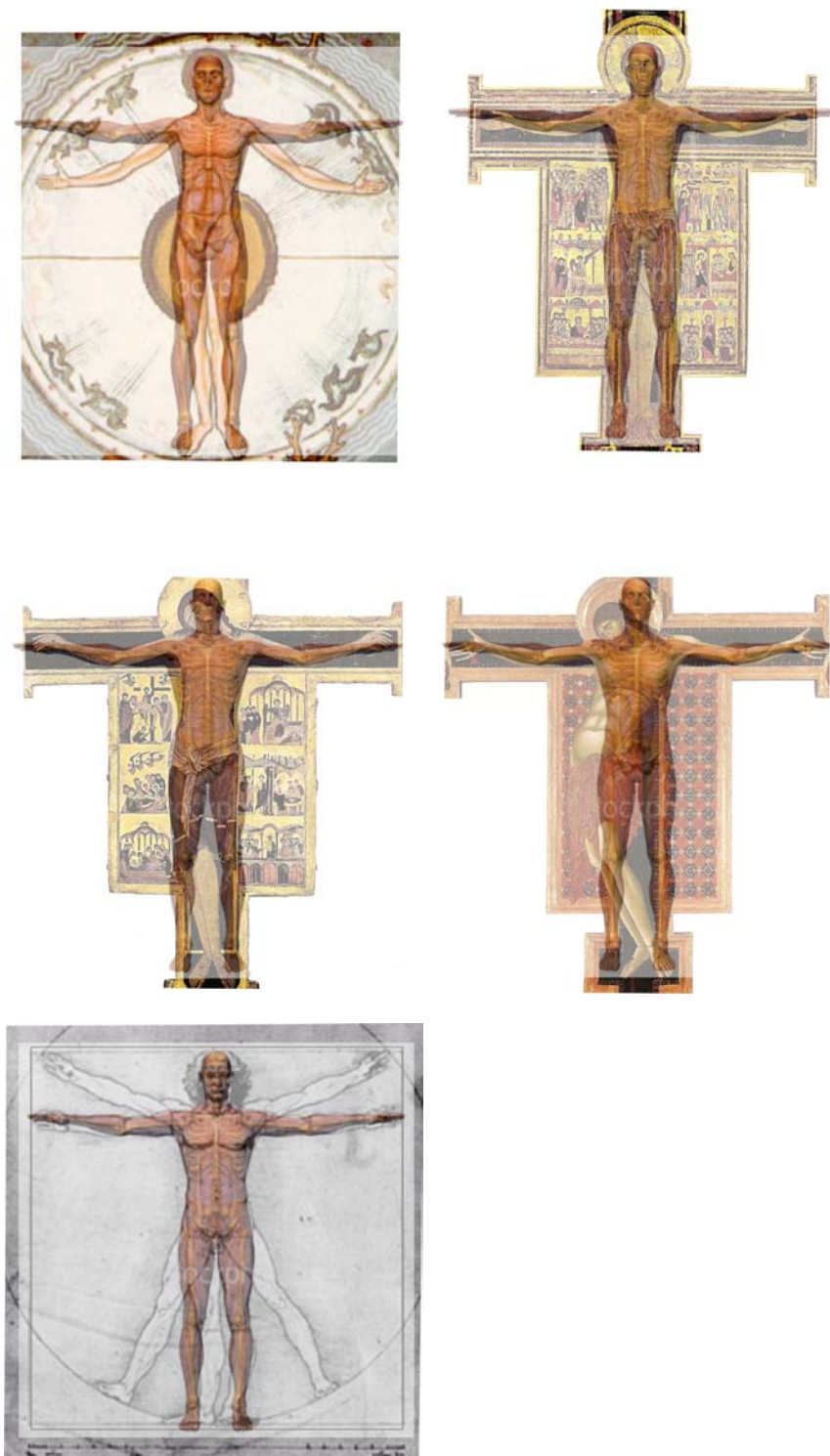
This *Universal Male* is considered to be the prototype of *Vitruvian Man* (1492, fig 4) conceived by Leonardo da Vinci (1452–1519) (*Encyclopedia Britannica* 2005. Sv “Leonardo da Vinci”) and makes a perfect model for portraying a man with arms outstretched as if hung on a cross.

I used the graphics applications in CorelDRAW X3 to test Chiellini’s theory, that is, that the San Domenico Arezzo *Crucifix* followed certain Church dogma for universal proportions based on Hildegard of Bingen’s interpretation of Vitruvius, and that this also applied to earlier crucifixes, for example, the Pisa crucifixes already mentioned. From the results of this experiment (exp 3) it can be stated that the Christ figure from the San Domenico Arezzo *Crucifix* is, indeed, “Vitruvian,” comparing well to Leonardo da Vinci’s *Vitruvian Man*, drawn two hundred years later. Vitruvian proportions may be perfect in a stereotypical sense, that is, a well-proportioned, physically-toned male. However, these proportions should be judged as normal, as they are also found in a modern anatomical diagram of an adult male. Therefore although “ideal,” Vitruvian proportions are not unnatural. I also found that Pisa *Crucifix No 15*, from the same era as Hildegard of Bingen, is not proportioned to Vitruvian man. The arms are too short, which has the overall effect of making the body proportionately elongated. On the other hand, the slightly later Pisa *Crucifix No 20* does follow Vitruvian proportions. One can conclude that, while applied quite systematically, Vitruvian proportions were not dogmatically required by Church commissioners of wooden crucifixes in the middle ages in Italy.



Experiment 3. Figures placed inside a box of 5 cm² show the different attitudes and concerns of various artists for the proportions of a human male, particularly with reference to the Vitruvian law which states that the length of a man's outspread arms is equal to his height. (From left: *Universal Man*, *Pisa Crucifix No 15*, *Pisa Crucifix No 20*, *San Domenico Arezzo Crucifix*, *Vitruvian Man* and a modern anatomical drawing.)

In a second experiment (exp 4)⁷ I made an extra copy of the modern anatomical drawing, and used the **Interactive Transparency Tool** to make this copy of the drawing 50% transparent. In order to compare the anatomical proportions I placed this transparency over the other figures from the sample. From this experiment I concluded that the *San Domenico Arezzo Crucifix* is more sophisticated in anatomical accuracy in comparison to the Pisa crucifixes.



Experiment 4. Figures superimposed with a modern anatomical drawing at transparency 50%, which helps to make a more accurate comparison between the medieval artists' concern with anatomy, and a modern understanding of how the skeleton and muscular frame of the average human male is presented. (From top left: *Universal Man* superimposed with a modern anatomical drawing at transparency 50%, *Pisa Crucifix No 15* with the same transparency, *Pisa Crucifix No 20* with the same transparency and the *San Domenico Arezzo Crucifix* with the same transparency, and bottom Leonardo's *Vitruvian Man* with the same transparency overlaid.)

However, the early Pisa crucifixes cannot be dismissed as totally unrealistic. In *Pisa Crucifix No 15* the sternum is well placed, but the ribcage too narrow in comparison to the modern anatomical drawing. The lateral torso is narrower, but the pelvis, knees and ankles are well placed. The arms are shorter by almost a hand's length. The sternum of *Pisa Crucifix No 20* is comparable in execution to *Pisa Crucifix No 15*. The lateral torso is narrower, but the hips are comparable. However, this figure of Christ also has relatively elongated legs. In terms of the medieval examples, the Christ figure from the *San Domenico Arezzo Crucifix* fits best with the transparency of the modern anatomical drawing. The lateral torso is well defined, as is the height of the sternum and the shape of the ribcage. The arms are slightly elongated over the modern anatomical drawing, but the muscles are accurately placed. The pelvis, knees and ankles are all comparatively placed. However, the left shoulder is twisted and distorted, and looks almost as if it has been dislocated.

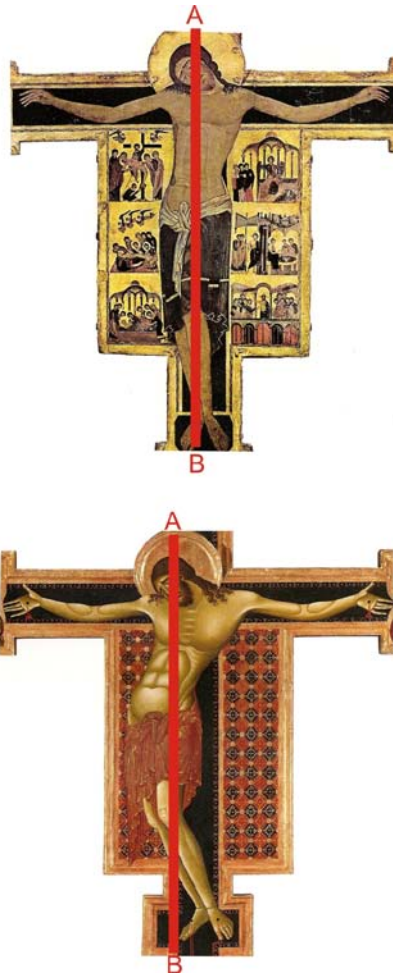
Chiellini also notes the particular feature of the distorted shoulder in the *San Domenico Arezzo Crucifix* and considers it part of Cimabue's innovative techniques.

Cimabue preserves this basic composition [that of *Vitruvian Man*], but he softens its rigidity by introducing a whole series of variations intended to stress Christ's suffering. The way the head is inclined towards the shoulder, for example, is accentuated by the position of the halo, which is quite definitely off-centre with respect to the vertical axis of the cross; and the left shoulder is placed asymmetrically to the right one, because the weight of the head falling to one side makes the muscles contract; lastly, the limp, curved body is bent sideways covering almost all the ornamental background (Chiellini 1988:12).

However, it can be stated that although this slipping of the halo is more exaggerated in the *San Domenico Arezzo Crucifix*, the slide actually started

earlier, and can already be seen in *Pisa Crucifix No 20*. Likewise the curving of the body sideways is not without precedent, and is found in such early prototypes as the *Hosios Lukas crucifix*. And again, the asymmetry of the left shoulder is also evident in the early *Pisa Crucifix No 20*, although, it can be said, not as obviously as the *San Domenico Arezzo Crucifix*.

Nevertheless, what is seemingly unique is the placement of the feet in the *San Domenico Arezzo Crucifix*, which are not in line with the centre of gravity (exp 5). This means that the model for the *San Domenico Arezzo Crucifix* appears not to have had his weight on his feet. This, perhaps, is the most exceptional departure from earlier models, and the way this effect was achieved may also account for the idiosyncratic seemingly-dislocated left shoulder. I postulate that the model had his arms over a support behind him, perhaps a rail or small wall. In this way, he was able to suspended himself, supported by his arms, and thereby remove the weight (and therefore also the centre of gravity) from his feet. This also had the effect of jutting the scapulae forward, but most particularly the left scapula, as the model is positioned to one side. Previous depictions of Christ crucified, whether shown triumphant or with more suffering, suggest most clearly that any model used was actually made simply to stand with his arms placed outstretched and, as in the case of *Pisa Crucifix No 20*, for example, with a slight relaxing of the body to one side.



Experiment 5. Line AB shows the different centres of gravity in Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix*.

It is important to stress that the evidence suggests that even the earlier Pisa crucifix artists may have looked occasionally at live models, while still remaining within the stereotypical church requirements. It cannot be claimed, therefore, that *only* the use of live models *per se* changed the way artists executed their paintings. As I have stated, the artists of the Pisa crucifixes cannot have been totally unfamiliar with the human form. In Pisa *Crucifix No 20* there are many anatomical and proportional accuracies, including the correct centre of gravity and the delineation of a contra-posture, that is, the chest and

abdominals follow one angle, while the hips follow the correct contradiction to this. This could imply that the much received opinion that medieval artists slavishly copied previous representations, or merely invented new ones out of their imaginations without using or looking at a real model, is extremely simplistic.

This takes me back to an earlier point that it is not only necessary to postulate *why* the representation of form changed but *how* it was able to change. The startling novelty of works like Cimabue's San Domenico Arezzo *Crucifix* have been put down, by Vasari, to the result of a young precocious artist willing to spend hours practicing by copying nature, that is, studying live models. Modern scholars, like Monica Chiellini, may simply credit the changes to "stormy historical events and a spiritual crisis" (Chiellini 1988:5–6). Chiellini, however, like many other scholars, does not offer any suggestions as to how artists achieved these innovations. The making of an individualistic artwork is not only in the posing of a live model. It is, rather, in the ability of the artist to transfer the perceived detail of a three-dimensional form onto a two-dimensional plane in such a way that an illusion of the original three-dimensional subject is extremely heightened. So, although we see the representations of figures such as that found on Pisa *Crucifix No 20* as being somewhat proportionately and anatomically accurate, we do not think of them as "realistic." The San Domenico Arezzo *Crucifix*, however, with its faithful rendering (especially considering the time period) and attention to modelling and form, is much more realistic to a modern eye.

It can be concluded therefore that, although the figure of Christ in the San Domenico Arezzo *Crucifix* is still very much stereotyped (that is, presented as a tall Middle Eastern male, with dark beard and moustache, and a full head of hair with dark locks flowing onto the shoulders), the representation has moved quite rapidly, in Italian terms, towards a new and startling distinctiveness. This is Christ as an *individual*, very carefully represented by the artist in astonishing detail. The model was perhaps a soldier, trained for war and exhibiting a high level of all-round muscle definition. He has the body of a particular type of male, in other words, an athlete. The abdominal, pectoral and lateral muscles are all prominently identified. The artist has shown not only biceps but also the muscles in the forearm, reemphasising muscular strength. The calf muscle bulges from behind the tibia of the left leg. The hands are anatomically drawn, with the abductor muscle shown at the base of the thumb, and the palms and fingers sectioned, depicting a hand that has worked at holding something heavy, or at manipulating a sword, perhaps. The hands, open and rigid, carry over the strength of the torso. Despite the remnants of a linear approach, the increased solidity of form and the representation of a heightened anatomical structure mark this work as a departure from the Italo-Byzantine style of the Pisa crucifixes. It has something new.

2.2.2 The representation of three-dimensional form

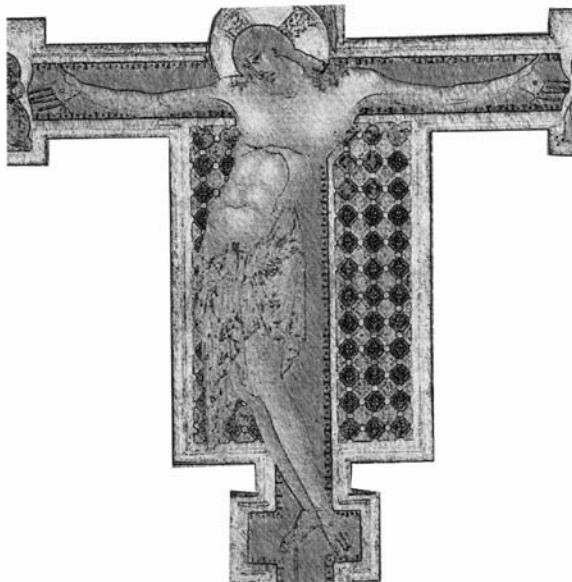
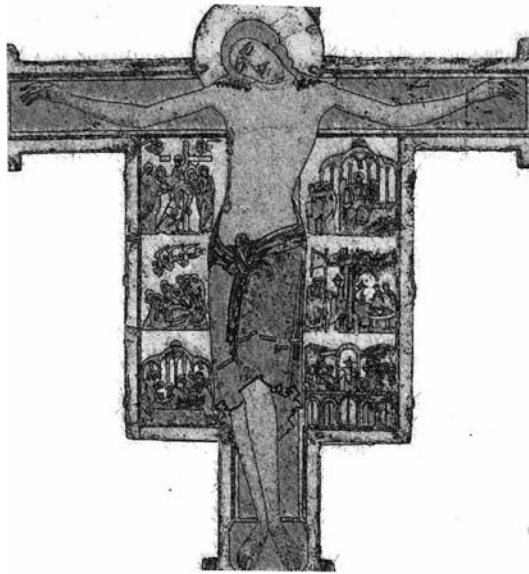
A preliminary drawing, what Italians call *disegno*, is often at the core of Italian painting, and it is certain that Cimabue worked from a complex *disegno*.⁸ It needs to be discovered whether this *disegno* was something new, and also to find out how far it departed from earlier examples, such as Pisa *Crucifix No 20*. Significantly, Cimabue's scientific and empirical approach to the human male form is quite revolutionary. In order to rigorously test this claim I subjected the surface of the San Domenico Arezzo *Crucifix* to a series of experimental tests using CorelDRAW X3. In order to develop a workable and legitimate set of diagnostic tools I used the research of the modern drawing theorist Betty Edwards, who was Professor Emeritus of Art at the University of California until she retired. Taking up her torch, her son Brian Bomeisler still gives so-called right-brain drawing classes in the United States, and lists the following prerequisites in learning how to draw well.

Bomeisler's five skill sets [taken from Edwards] are: the perception of edges using line or contour drawing, the perception of spaces within a drawing through the use of negative space, the perception of the relationships of angles and proportions also known as sighting, the perception of lights and shadows using light logic, and the perception of the whole or gestalt, which incorporates the previous four perceptual skills (Kaplan 2007:106).

Keeping in mind that Edwards' stated skills are twentieth-century skills, I will nevertheless use these clearly demarcated sets to "test" the efficiency of the underlying *disegno* in the San Domenico Arezzo *Crucifix*, and compare the results with the application of the same thorough testing to Pisa *Crucifix No 20*. In this way, it can be established if there really was a paradigm shift in *disegno*

between Cimabue and his predecessors. Once the full range of this shift is clearly demarcated, I will then consider the application of optical aids in Cimabue, as a way to explain the so-far unexplained innovation of his work.

Firstly, the outline, or contour drawing, of the San Domenico Arezzo *Crucifix* is, indeed, far more sophisticated than Pisa *Crucifix No 20* (exp 6). To compare the two paintings, I manipulated the images in CorelDRAW X3, using the **Art Strokes, Sketch Pad Tool** with the Graphite Pencil set to HB, and Style and Outline set to medium. In the San Domenico Arezzo *Crucifix* the contours of the arms flow around the scapulae into the hair line. In Pisa *Crucifix No 20*, the lines of the arms attach to the body in a jarring way, so that the arms look like thin, bendy appendages stuck onto the lateral torso. Further, in the San Domenico Arezzo *Crucifix* the underlying contour drawing strongly suggests the pull of the skin underneath the arm, thereby marking the armpits. In Pisa *Crucifix No 20* there is no demarcation of the armpits, and the line joins the body in a simplistic way. The hair in Pisa *Crucifix No 20* is outlined like a cap, whereas in the San Domenico Arezzo *Crucifix* the softness and individuality of strands of hair are clearly implied. The shape of the legs in the San Domenico Arezzo *Crucifix* shows an individual outline, as opposed to the Pisa *Crucifix No 20* where the line is straight, finite and simplistic, echoing the same naive approach of the arms.



Experiment 6. Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix* shown as improvised “sketches.”

If one considers carefully what is happening in these two representations, the underlying contour drawing of the San Domenico Arezzo *Crucifix* demonstrates that the artist replicated the shape of an actual man, as opposed to the artist of Pisa *Crucifix No 20* who has portrayed the stylised suggestion of arms, body, legs, head, hair, etc. This does not, however, automatically imply that the artist of Pisa *Crucifix No 20* was not drawing from a real model, but it

does show a comparatively lower level of drawing skill in terms of individuality, with less attention to how the thing being represented actually was. Brian Bomeisler explained the difficulties in contour drawings thus.

“The left hemisphere constantly interferes with your perceptions of what you are seeing,” he explained “You are working with symbols, and symbols come from the left hemisphere [of the brain].” The key to drawing successfully, he emphasized, is forcing the brain to move away from symbols – for example, to look at a human nose and actually draw what it looks like instead of drawing the shape that the [left] brain associates with a nose (quoted in Kaplan 2007:106).

Both Edwards and Bomeisler stress the importance of understanding negative space as the second skill of drawing, which is closely associated to contour drawing. “The *perception of negative spaces* is the second basic component of the global skill of drawing” (Edwards 1988:152, author’s original italics). To test this concept for the San Domenico Arezzo *Crucifix* and Pisa *Crucifix No 20*, I used a **Transformation Tool** in CorelDRAW X3, which inverts the colours of the bitmap and gives the appearance of a negative. This experiment (exp 7) shows how the negative image of the San Domenico Arezzo *Crucifix* startles just like a modern photographic negative. The negative shapes, both within and outside the body, are well-defined and complex, as for example, the shape the swaying body makes against the background of the cross. On the other hand, the negative spaces in Pisa *Crucifix No 20* emphasize the illustrative elements, as in the way the arms have been described, appearing curved rather than jointed. From this experiment I conclude that the Christ figure from the San Domenico Arezzo *Crucifix* is indeed very “modern” in its appearance, and that the artist has understood the concept of negative space.



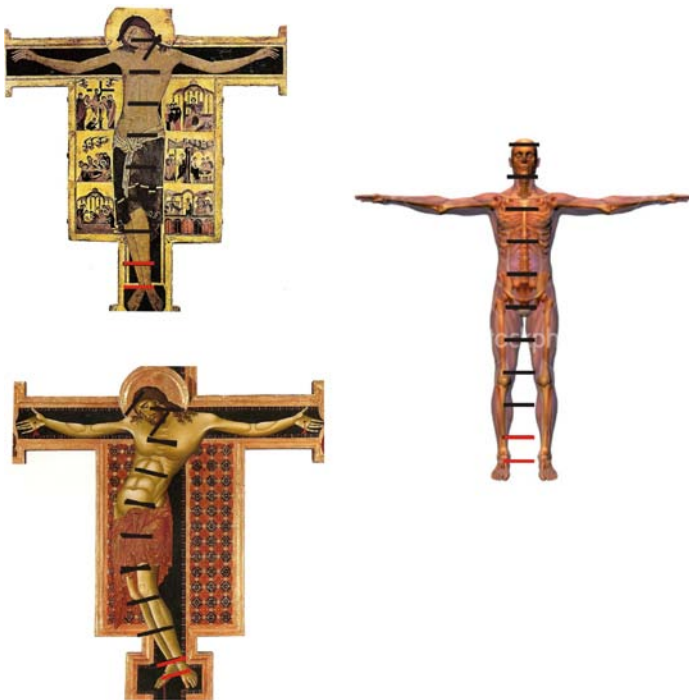
Experiment 7. Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix* transformed into the appearance of photographic negatives, using CorelDraw **Transformation, Invert Tool**.

We have no written record of whether or not early medieval artists, such as Cimabue, used “sighting,” the third skill identified by Edwards and Bomeisler. However, a valuable treatise on the art of painting by Florentine Cennino Cennini, which was written sometime towards the end of the 1300s, suggests that measuring was used to translate the correct angles and

proportions from the three-dimensional model onto the two-dimensional page. In *The Craftman's Handbook*⁹ Cennini describes how artists should proportion the male body.

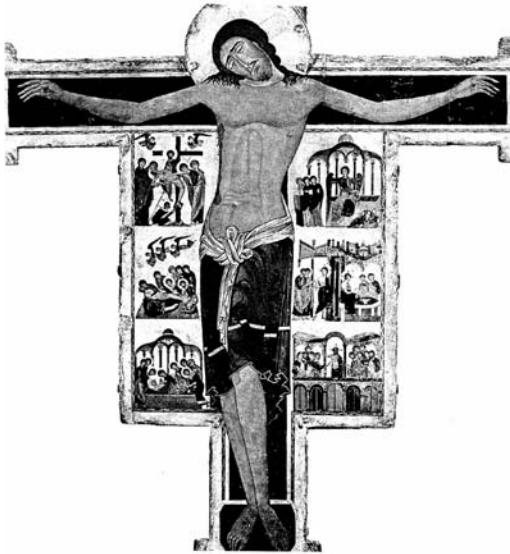
A man is as long as his arms crosswise. The arms, including the hands, reach to the middle of the thigh. The whole man is eight faces and two of the three measures [$\frac{2}{3}$] in length (Cennini 1933:49).

The “Vitruvian” proportion, that is, that “a man is as long as his arms crosswise,” has already been tested in the relevant samples. Cennini’s recommendation that the “whole man is eight faces and two of the three measures,” has, indeed, been followed by the artist of Pisa *Crucifix No 20* (exp 8). However, the proportions of the San Domenico Arezzo *Crucifix*, $9\frac{1}{3}$ faces, are more approximate to the proportions seen in the anatomical diagram of a modern man, that is, $9\frac{2}{3}$ faces.



Experiment 8. The proportions of Pisa *Crucifix No 20* are similar to those described by Cennino Cennini in the fourteenth century, whereas the proportions of the San Domenico Arezzo *Crucifix* are closer to those of the anatomical diagram of a modern man.

The fourth skill defined by both Edwards and Bomeisler is what they call “light logic” (Edwards 1988:204). Edwards claims that a competent artist has “the trick ... to supply enough information in the form of shadow shapes and light shapes to ‘set off’ the imaging process in the minds of those who look at ... [the] drawing” (Edwards 1988:205). Bearing in mind that the San Domenico *Crucifix* and Pisa *Crucifix No 20* are panel paintings, the underlying light logic of the artists’ invention can, nevertheless, be estimated by exaggerating the contrasting of light and shadow. To do this I converted both images to Greyscale (8bit), and adjusted the **Contrast** to 100% (exp 9). The artist of the San Domenico Arezzo *Crucifix* shows a sophisticated comprehension of light and dark, and exhibits a strong sense of light logic. The central figure of Christ on the San Domenico Arezzo *Crucifix* is marked by areas of strong highlights, especially predominant on the muscle groups like the pectorals, biceps, as well as on the face. Further, medium shadows are well defined, and there are some very dark areas as well, such as under the armpits and between the legs. On the other hand, the artist of Pisa *Crucifix No 20* has only marked a very rudimentary suggestion of light and dark, with an overall grey tone, and therefore cannot be said to have exhibited a developed sense of light logic.



Experiment 9. Comparing and contrasting the “light logic” in Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix*.

The four drawing sets of Edwards and Bomeisler lead up to the fifth skill they identify, which is an artist’s sense of the *Gestalt*, or the “thingness of the thing” (Edwards 1988:204) being represented. Edwards (1988:204) states that “perception of the Gestalt ..., [is] usually marked by a sudden appreciation of the uniqueness, complexity, beauty, and ‘rightness’ of the thing being drawn.” I call this the represented thing’s individuality. Summing up the “skills sets”

applied to Pisa *Crucifix No 20*, and comparing the results to the same sets applied to the San Domenico Arezzo *Crucifix*, it can be stated that the artist of the San Domenico Arezzo *Crucifix* has captured the uniqueness of *this* Christ crucified. In contrast however, the artist of Pisa *Crucifix No 20* has not captured the “‘rightness’ of the thing being drawn,” which remains a generalised and simplified depiction of *a* Christ crucified.

This applied experimental testing reveals a unique drawing skill in the San Domenico Arezzo *Crucifix*, now attributed almost universally to Cimabue. Such skill has, furthermore, been uncovered in recent diagnostic tests carried out for the restoration of the crucifix by the Soprintendenza of Arezzo between 1997 and 2001.

[A] series of diagnostic photographs were made with ultraviolet light and infrared reflectography. The infra-red camera, a precision instrument capable of penetrating and reproducing what exists beneath the paintlayers, revealed the amazing preparatory underdrawing the artist had put down directly on the *gesso* ground before the first application of paint. Perfect photographs have made visible the anatomical underdrawing of Christ just as Cimabue had outlined and modeled it, before turning to his precious paints or gilding. We [the restorers one presumes] are stupefied by the utmost naturalness and soft tonalities of the modulation, rather intense in shaded areas and appearing more “modern” and realistic than the resulting painted image, whose bodily contours revert back to the geometric patterns so typical of Byzantine models. However, to tell the truth, within these schematic presentations [of the final painted figure] one senses the vibrations and strength of a living body [in the drawing underneath] whose beauty and perfection of forms, utterly enhanced after the restoration, are embraced by a light that gently touches well-toned muscles, highlighting their fullness (Maetzke 2001:30).

This infrared reflectography reveals an underdrawing that fully supports my experimental findings, that is, that Cimabue was a great designer, capable of drafting a figure in a way that equates admirably with the best skills of the Renaissance (Leonardo da Vinci, for example). Maetzke, and her fellow

restorers, were, seemingly, left breathless by his skill, and she refers specifically to “forms, ... embraced by a light that gently touches well-toned muscles,” what Edwards and Bomeisler would have called the artist’s “light logic.”

So great was Cimabue’s attention to the underdrawing that “he produced a monochromatic first draft underneath the painted one” (Galoppi & Ugolini 2001:38). He achieved this by outlining the positioning of the figure on the cross (Galoppi & Ugolini 2001:37). The artist then “traced the entire design of the composition with a brush soaked in ink, ... delineating as well the entire method of shading that was to be executed also for the painted drapery folds and for the hair and the beards, exactly as they appear in the finished version” (Galoppi & Ugolini 2001:37–38). Built up in thin strokes the tonality of the muscles is appreciably even more realistic in the underdrawing than in the actual painting itself (fig 5).

The question remains however: who (or what) taught Cimabue to “*inventare*” with such skill? Vasari tells us that he was trained by the Greek masters who were called to Florence to reintroduce the lost art of painting (Maginnis 1994:147). However, Vasari states that the work these Greek masters completed was then “obscured and consumed by time” (quoted in Maginnis 1994:147). We have no way of judging their skills, but can strongly assume that they were Byzantine. In any case Vasari claims that Cimabue was soon so much better than they were. “[I]n a short time nature aided [Cimabue] ... such that in drawing and colouring he surpassed the masters who had taught him” (translated and quoted in Maginnis 1994:147). How did Cimabue achieve

this? It is certain that some people have a natural talent to draw better than others, but here we are talking of an historical situation where one man, one artist alone, makes a quantum leap in terms of set skills. Cimabue may explain Giotto, a notion reinforced since J.A. Crowe and G.B. Cavalcaselle in 1864 (Maginnis 1994:150), but who, or what, explains Cimabue? How did Cimabue gain such a seemingly intimate knowledge of human anatomy, reinforced in the application of all the drawing skills sets proposed by modern researchers Edwards and Bomeisler?

One way in which artists did seek to improve their depiction of anatomy was to be involved in dissection. However, even for medical purposes dissections were extremely rare in Cimabue's time. Cennini (1933:58) still believed that men had one less rib than women, and Vasari was to credit only the much later Florentine artist Antonio Pollaiuolo (c.1431–1498) as the “first master to skin many human bodies in order to investigate the muscles and understand the nude in a modern way” (translated and quoted in Bull 1965:73). Perhaps Vasari did not fully appreciate just how competent Cimabue was in the representation of the underlying anatomical structure of the human male, as proved by the many experiments recorded above, and the revelations of modern infra-red reflectography.

The startling individuality of Cimabue's San Domenico Arezzo *Crucifix* appears almost overnight from a heritage of Italo-Byzantine *disegno* that was still relatively naïve. The hindrance to believing that Cimabue achieved such a leap simply by practicing his drawing, and exercising a special talent, is that the brain comes between the human lens, that is, the eye, and the hand's

representation of three-dimensional form onto a two-dimensional support. Whether one buys into Edward's right-brain theories for drawing, or not, it is undoubtedly true that symbolic abstraction hinders visual literacy (Edwards 1988:11), and Italo-Byzantine *disegno* was all about symbolic abstraction. In drawing, the artist's logical brain constantly interferes with the "thingness" of the seen thing, and refers the artist to shorthand for the thing, so that an individual face becomes a general face, and so on, as seen in Pisa *Crucifix No 20*. Yet suddenly, around 1270, Cimabue springs into this Italo-Byzantine artistic ring, drawing with Gestalt, like Athena appearing fully formed from the brain of Zeus. All this happened just a few short years after Roger Bacon's treatise of optical theory, explained in his *Opus Majus*, arrived in Italy together with a lens and a description of how image projections can be created.

The San Domenico Arezzo *Crucifix* is considered by some modern critics to pre-date Cimabue's visit to Rome in 1272, based on the assumption that it does not have any characteristics that could have been influenced by Roman artistic trends (Maetzke 2001:24). However, the crucifix shows many features that could link it to an optical invention, and therefore a date of around 1272, when information about image projections entered the papal orbit, becomes absolutely appropriate. Faced with an image projection Cimabue appears to have focused on this phenomenon, while taking little notice of what was going on around him in the artistic circles of Rome.

Notes to this section

¹ Erano per l'infinito diluvio mali che avevano caciato al disotto et affogata la misera Italia non solamente rovinate quelle che chiamar si potevano fabbriche, ma – quel che importava assai più – spentone affatto tutto il numero degli artefici, quando, come Dio voles, nacque nella città di Fiorenza l'anno MCCXL, per dare i primi luci all'arte della pittura, Giovanni cognominato Cimabue, della famiglia de' Cimabuoi in quel tempo nobile” (Vasari quoted in Maginnis 1994:161–162).

² [The first Italian paper mill in Italy was begun in the 1270s, in Fabiano (Hallam 1853:458), and any “sheets” that Cimabue might have been able to use would have had to have been made from sheep’s parchment, at incredible expense. Vasari is most obviously expressing a Renaissance sentiment that to become a great master of painting required years of arduous training, and hours and hours of practice drawing (on paper).

³ “Avvenne che in que’ giorni erano venuti di Grecia certi pittori in Fiorenze, chiamati da chi governava quella città non per altro che per introdurvi l’arte della pittura, la quale in Toscana era stata smarrita molto tempo. Laonde, avendo questi maestri prese molte opere per quella città, cominciarono in fra l’altre la capella de’Gondi allato a la principale in Santa Maria Novella, della quail oggi dal tempo la volta e le facciare sono molto spente e consummate. Per il che Cimabue, cominciato a dar principio a questa arte che gli piaceva, si fuggiva spesso da la scuola e tutto il giorno stava a vedere lavorare que’ maestri” (Vasari quoted in Maginnis 1994:162).

⁴ “E dicesi che mentre Cimabue ditta tavola dipigneva in certi orti vicina l’orta S. Piero, non per altro che per avervi buon lume e buon aere e per fuggire la frequenza degli uomini, ...” (Vasari quoted in Maginnis 1994:162).

⁵ “[L]a quale, perciò ch’ ancora era state veduta da alcuno, mostrandosi al re, subito vi concorsero tutti gli uomini e tutte le donne di Fiorenza con grandissima festa e con la maggior calca del mondo” (Vasari quoted in Maginnis 1994:162).

⁶ Venice, for example, plundered four huge bronze horses for its Piazza San Marco, and a jewelled plaque that became the Pala D’Oro altarpiece of the cathedral (Eimerl 1967:38).

⁷ The idea of using transparency overlays of digitised images is also found in Falco & Hockney 2000; 2003; and in Hockney 2001:??).

⁸ Hockney, and others, sometimes make something of a big deal of the fact that Caravaggio left no drawings (see Hockney ???). However, I have discovered that Rubens most definitely made use of image projections, and he was a competent draughtsman. The fact that artists may have drawn, either freehand or using an image projection, or that they may have made preliminary drawings, is not, therefore, mutually exclusive to their use of image projections.

⁹ A copy of one of Cennini’s manuscripts is dated 1437, which is therefore thought to be the date of writing (Wikipedia Online Encyclopedia Sv. “Cennino Cennini.”). This is highly unlikely, and it is more probable that the manuscript was penned towards the end of the 1300s. Cennini claimed to have been born in Colle Val d’Elsa, and have been a pupil of Agnolo di Taddeo of Florence, who was a pupil of his father Taddeo, who had been a pupil and follower of Giotto (Cennini 1933:2). Using this genealogy Cennini’s birth can be placed sometime around 1350.

CHAPTER 3

Duccio, master of the individual narrative

3.1 CIMABUE AND DUCCIO

3.1.1 An optical relationship

The truth of the relationship between Cimabue and Duccio is shrouded in mystery. Scholarly opinion as to the nature and extent of their association has vacillated. Renaissance chroniclers were inclined to ignore Duccio's contribution to the foundations of naturalism in Italian painting, and readily assigned one of his most important early works, the Rucellai *Madonna* (1285, plate 13), to Cimabue. This large altarpiece was housed in the Church of Santa Maria Novella in Florence, which was built by the Dominicans in the latter part of the thirteenth century with donations from the Rucellai family.¹ From the early fifteenth-century commentary of Dante, through other Florentine writers like Albertini, Billi and Gelli, to Vasari in the mid-sixteenth century, it was believed that this prototype of naturalism came from the brush of Cimabue (Maginnis 1994:150).

[A]lthough near the end of the *Vite*, in the *Life* of Michelangelo, Vasari harkens back to Giotto, it was in fact with Giotto's supposed master that he began. Cimabue and the story of his appearance in an artistic wilderness gave the book its essential shape: what we call the Renaissance was initiated by a Florentine Baptist and found its fulfillment in a Florentine Saviour. Art began and ended in Florence (Maginnis 1994:150).

Recent scholarship leaves any liaison between Cimabue and Duccio unresolved. Some critics have tried to develop Roberto Longhi's theory that there was a teacher-pupil relationship between Cimabue and Duccio (Bologna 1983:337). Others, like Duccio biographer John White, agree "in firmly rejecting the idea that Duccio was Cimabue's pupil or collaborated with him at Assisi or anywhere else" (Bologna 1983:337).

In consideration of this thesis for an essential optical intervention in the foundations of an individualised naturalism, Cimabue can, in fact, be supported as a "John the Baptist" of Italian painting, using an art form which took a fundamental turn in a new direction under his influence. However, the artwork that heralded this new direction was a crucifix commissioned for a small church in the byway Tuscan town of Arezzo, and not the long held Holy Grail of Italian naturalism, the Rucellai *Madonna* in Florence. This leaves open a number of interesting questions. For example, what is so special about the Rucellai *Madonna* that it held, for so long, its pride of place among Florentines, despite being a work by the marginalised Sieneese Duccio? And why was the revolutionary conception of the San Domenico Arezzo *Crucifix* ignored for so long, with the work only in the last century being attributed to Cimabue? Further, why has establishing a possible working relationship between Cimabue and Duccio been so divisive and controversial? And finally, and most importantly for this thesis, what is the significance of any relationship between Duccio and Cimabue in proving an early use of optical aids in the introduction of individuality into Italian painting at the end of the thirteenth century? These are questions I will attempt to answer in due course.

Hayden Maginnis (1994:151) claims that modern art historical research dealt with the re-attribution of the Rucellai *Madonna* from Cimabue to Duccio by simply replacing the preeminence of this panel with one that was more convincingly by Cimabue.

[S]cholarship, like nature, abhors a vacuum; and so Cimabue's *Sta. Trinità Madonna* ... a work Vasari only included in the second edition of the *Lives*, came to take the place of the Rucellai *Madonna* as the picture announcing the rebirth of painting. Thus Vasari's vision was redeemed, while Duccio's panel was relegated to a minor place, firmly locked in simplified descriptions of the "lyrical" but conservative Sienese school (Maginnis 1994:151).

It is hard to gauge whether this sentiment is really true, and perhaps Maginnis's article, "Duccio's Rucellai *Madonna* and the origins of Florentine painting" (1994), even helped to re-stimulate an interest in the Rucellai *Madonna*. Certainly this panel hangs together with Cimabue's *Santa Trinità Madonna* (c.1280–1285, plate 14) and Giotto's *Ognissanti Madonna* (c.1310, plate 15) in a single large room at the entrance to the section of medieval painting at the Uffizi Gallery in Florence. Nonetheless, Maginnis's outline of what he sees as the new features in the Rucellai *Madonna* are helpful in trying to explain how it held its prominence for many centuries as the harbinger of a new type of naturalism in Italian Duecento painting.

One of the first noticeable characteristics that Maginnis sees as new, is the sense of weight given to the throne in the way the angels appear to bear it towards the viewer.

The image is a vision not of ascent (as some writers would have it), not even of a timeless paradise, but rather of a descending glory. The six angels seem to bear the Virgin's throne, complete with dais, toward us (Maginnis 1994:151).

Maginnis (1994:151) sees the way that the angels are shown kneeling as part of this revolutionary invention. Maginnis (1994:152) then turns to the depiction of form beneath fabric, which “evokes hidden anatomy.” The most surprising detail of this new attention to individuality is seen, according to Maginnis, in the depiction of the Madonna.

A series of hairpin folds modestly suggests the form of the Virgin’s right breast. And more than twenty years before Giotto’s Ognissanti *Madonna* ... modelling vividly describes the placement of her right knee within the mantle (Maginnis 1994:154).

Maginnis (1994:154) calls this new approach “anatomical logic.” Along with this he also claims that the Rucellai *Madonna* exhibits an attention to “‘modern’ pictorial space” (Maginnis 1994:153).

In earlier Sieneese panels image and picture surface were essentially one, and the ground not so much a field occupied as an area filled. Here, [in the Rucellai *Madonna*] the gold ground becomes an habitable ether, and as throne and frame are clearly separated, so throne and picture plane are clearly divided by the lower step of the dais. The conceit was highly original and destined to have long-lasting ramifications (Maginnis 1994:153).

However, these points of absolute originality are somewhat difficult to sustain when the Rucellai *Madonna* is held up against the San Domenico Arezzo *Crucifix*, and even the Santa Trinità *Madonna*.

For example, the figure of Christ in the San Domenico Arezzo *Crucifix* is a much earlier instance, by some fifteen years,² of a “modern” depiction of spatial logic than is found in the Rucellai *Madonna*. Christ is firmly planted on the cross, which forms a *background* to his slumped body. The right hip sways out into pictorial space and is very clearly on top of the patterned cloth depicted as hanging *behind* the figure. This spatial logic is not seen, however, in the earlier crucifix examples such as Pisa *Crucifix No 15* and Pisa *Crucifix*

No 20, where the Christ figure is not integrated into the narrative spaces of the scaled-down figures on the side panels. Further, Maginnis's definition of "anatomical logic" has been shown in chapter two to be extremely advanced in the San Domenico Arezzo *Crucifix*. In fact, Maginnis's reference to the jutting knee underneath the mantle in the Rucellai *Madonna* is not a sustainable example of a medieval artist's new way of approaching so-called naturalism. This raises my earlier point that even before Cimabue's first use of optics medieval Italian artists did not produce figures that can only be considered unrealistic. They certainly looked at the anatomy of real people, but interpreted what they saw in an abstract way. In the Sienese panel of *Madonna of the Large Eyes* (early 1200s, plate 16) the artist has clearly attempted to portray the cloth in such a way that it shows a tautness around the Virgin's protruding knees, in order to give the impression that she is sitting down. Finally, the portrayal of the angels as bearing the weight of the throne in the Rucellai *Madonna* is repeated in the Santa Trinità *Madonna*. Cimabue too has depicted the angels as if they are bearing up the throne.

There are two crucial aspects, in terms of a new type of individuality being introduced into Italian medieval painting, which are seen in the Rucellai *Madonna* and which Maginnis has failed to address. The first is in the attempted representation of the Christ figure *as a child* (exp 22). This juvenile figure seated on the Madonna's lap in the Rucellai *Madonna* is a clear departure from the more usual Italo-Byzantine style of simply shrinking an adult figure, and incorporating it into the area in front of the Virgin, as seen in the *Madonna of the Large Eyes* and the Bigallo Master's *Madonna and Child*

Enthroned (c.1225–1250, plate 17). Duccio's shows a fresh approach, with an interest in depicting a real child's portrait as seen also in Cimabue's *Santa Trinità Madonna*.

The child's portrait by the Bigallo Master is clearly out of proportion to an average child's facial proportions. The chin is far too large, and the eyes are too high in the head. The portrait lacks the large forehead noted in a child's anatomy. On the other hand, the *Santa Trinità* Christ child is much more in proportion to accepted standards of measuring anatomy. The eyes and nose are correctly placed, and the forehead is much larger than an adult's would be. The mouth, however, is slightly high up. Finally, the *Rucellai Madonna* Christ child is a faithful and delicate rendering of a child's portrait, with all features correctly placed, which certainly suggests an optical projection could have been used.



Experiment 22. Figures showing a comparison of the facial proportions of the *Rucellai Madonna* Christ child, the *Santa Trinità Madonna* Christ child, and the Bigallo Master Christ "child."

The second aspect of a new type of individuality in medieval Italian painting is the realistic representation of saints and prophets in the medallions

that surround the Rucellai *Madonna*. These lively individual portraits (exp 23) are about 12 cm in diameter, large enough for their uniqueness to be fully appreciated when viewed in real life. The configuration of an optical system to achieve these roundel figures is relatively simple, with a lens of f 30 cm. Indeed the figures are all the same size, with the head measuring approximately 3 cm, so that the magnification can be calculated as below:

$$M = \text{Size image/size object}$$

$$M = 3/22$$

$$M = 0.14$$

Knowing the magnification, and estimating a focal length of 30 cm, it can be calculated that if based on projections the models were all standing about 2.44 m from the lens.

$$M = f/(S_o - f)$$

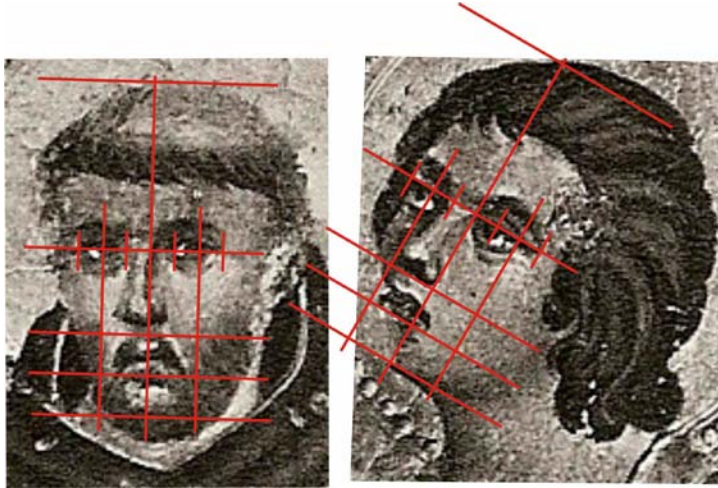
$$0.14 = 30/(S_o - 30)$$

$$(S_o - 30) = 30/0.14$$

$$S_o = 30/0.14 + 30$$

$$S_o = 244$$

Duccio's little medallion portraits are, therefore, almost exactly the same size as estimated for the real image size of the figure of Christ in Cimabue's San Domenico Arezzo *Crucifix*, where I calculated an image distance of 2.06 m and a magnification of 0.17. This strongly suggests that Duccio and Cimabue were not only both using optics, but also using the same lens system. Duccio leaves his images at the size of the reduced real image, whereas Cimabue enlarges his image to create the full-size figure of Christ crucified.



Experiment 23. Figures showing a comparison of the facial proportions of the medallion images.

Because the roundel portraits are relatively small in comparison to the figure of the Virgin, in most reproductions of the Rucellai *Madonna* they are barely visible. Yet their individuality is undeniable. Duccio has used a number of real models of different ages, and applied a variety of colours and styles to their garments. The essential individuality of these medallions reiterates the introduction of real people as prophets, first seen in Cimabue's *Santa Trinità Madonna*. The single individual model used for the portraits of these prophets has features which very closely resemble a Chinese physiognomy.³ This, together with the characterful way the figures have been portrayed, was highly innovative for the time. A Byzantine mosaic of the Fathers of the Church (c.1250, plate 18) in Palermo, shows the more usual presentation of Middle Eastern type figures that have elongated and stylised features, and sombre expressions. Comparing the portrait of Abraham, in the *Santa Trinità* altarpiece, with the portrait of an ancient Chinese prophet Mencius highlights many remarkable correlations (fig 14). The portraits show the same narrow eyes, the same characteristic eyebrows which arch highly and curve upwards.

They have the same shape of nose, high cheekbones, and similar expressions. Such a closely observed and detailed empirical study of what might have been a Chinese model gives an exotic touch to this large and innovative panel.⁴

The portrait roundels on the Rucellai *Madonna* are, according to Ferdinando Bologna, “the most Cimabuesque of the figures introduced by Duccio” (Bologna 1983:340). Like the figures of the prophets on the Santa Trinità *Madonna*, they are also the most individualistic aspects of the panel. However, unlike Cimabue’s prophets who are represented by a model chosen, it would seem, for his exotically arcane visage, Duccio’s roundel models are more common. Duccio is applying the benefits of an optical projection, as an aid to representation, in a new way, thereby taking Cimabue’s application of optical technology a step further. The older Cimabue used optics more circumspectly. In this regard the very beauty of the man chosen to model for the San Domenico Arezzo *Crucifix* comes to mind. On the other hand, Duccio chooses his models in a way that moves Italian painting in a new direction. Much more so than Cimabue, he begins to explore the character, personality, expression and human emotion of the ordinary people around him.

Yet Duccio’s debt to Cimabue cannot be denied. The similarities between the Rucellai *Madonna* and the Santa Trinità *Madonna* are much more marked than any differences. The Santa Trinità *Madonna* has an obvious sense of primacy; it is an older work by a more mature artist whose very roots are Italo-Byzantine, for example, in the linear approach to the depiction of the mantle with highlights of gold filigree, which recalls the style of the loin cloth in the San Domenico Arezzo *Crucifix*. The depiction of draping fabric in the Rucellai

Madonna is much more expertly controlled in terms of gradations of light and dark, and therefore appears far more naturalistic. Duccio has looked carefully at the way Cimabue portrayed the child, has followed certain aspects of the representation of the Madonna, and has brought the angels into the earthly realm in a way that echoes Cimabue's earlier depiction. And, most importantly, he has individualised the prophets and church fathers of the roundels, undoubtedly through the direct manipulation of optical projections.

The masterful qualities of the Rucellai *Madonna* left art historians scrambling for an explanation, when it became undeniable that the attribution should go to Duccio. Duccio was, historically, the creator of the *Maestà* (1308–1311, see plate 28), now in the Museo dell'Opera del Duomo in Siena. Before 1285 he was recorded only as a small-time painter who worked, it would appear, on painting the covers of account books (White 1979:18). Apart from anything he was Sienese, and the Rucellai *Madonna* was commissioned by the Dominican Laudesi for the Church of Santa Maria Novella in Florence.

The discussion of the possible relationship between the Florentine and the Sienese master has its background the reasons [sic] which led the Florentine memorialists of the fifteenth and sixteenth centuries, followed by Vasari in 1550, to attribute the Rucellai *Madonna* to Cimabue, although the letter of commission dated 15th April 1285 – rediscovered by the Dominican Fineschi in 1790, but first used critically by Wickhoff in 1889 – pointed clearly to the youthful Duccio. As is well known, not all scholars accepted at once the link between document and painting, and a lengthy argument ensued. It is noteworthy, however, that while for many the issue was a simple alternative between Cimabue and Duccio, others increasingly saw the possibility of some form of collaboration between the two artists (Bologna 1983:334).

If there was such a collaboration it would seem therefore that the most likely answer as to why it existed at all – considering the hostilities that always

separated Siena and Florence on so many aspects – was that the application of optics, at that time, was generally better known by the Dominicans.

Duccio's *Maestà* is a huge and complex altarpiece which was commissioned in 1308 by the Master of the Works of Siena's cathedral (White 1979:80). Siena itself was a Dominican stronghold, and is associated with such famous Dominicans as Blessed Ambrose (1220–1286) and St Catherine of Siena, a Dominican nun (1347–1380).⁵ Duccio's other Dominican commissions included the *Virgin and Child with Sts Dominic and Aurea* (c.1300, plate 19) now in London (Freni 2000:59) and possibly also the *Crucifixion with Sts Nicholas and Gregory* (c.1300, plate 20) now in Boston. It is not inconceivable therefore that Duccio was called to Florence because of his Dominican connections, and trained, probably in secret, under Cimabue. This supposition is strengthened by the fact that for many centuries the Rucellai *Madonna* was attributed to Cimabue and not to Duccio. Certainly Duccio had advantages over Cimabue, those being his relative youth, an already accessible tool in the optical projection, and a master to work under who had already ironed out many of the formal problems and demands of his craft.

Curiously, Cimabue's relationship with the Dominicans seems to have terminated around the time that Duccio must have begun work on the Rucellai *Madonna*. It may even have been that Cimabue fell out with the Dominicans, hence the Dominican commission of the Rucellai *Madonna* went to the relatively unknown Sieneese artist with strong Dominican connections. From around 1285 onwards Cimabue seems to have accepted, or been offered, commissions only from the Franciscans. The Santa Trinità *Madonna* was a

Franciscan commission (Chiellini 1988:49), and sometime around 1280 Cimabue went to work on the decorations of the new Basilica of St Francis at Assisi (Chiellini 1988:16). The one known exception is a smallish panel attributed to Cimabue, the Contini Bonacossi *Madonna* (no date, plate 21), which has depictions of both St Francis and St Dominic.

These religious sympathies, and the background struggles between the Franciscans and Dominicans for control of the Church, which clearly affected the fate of Roger Bacon as has been mentioned, could go some way to answering the questions I posed at the beginning of this section. The Rucellai *Madonna* may well have been marginalised a lot earlier if the true provenance of this painting had been understood by the Florentines from the beginning, that is, that it was by the Sieneese Duccio and not the Florentine Cimabue. However, the Rucellai *Madonna* is a much more advanced and more naturalistic work than Cimabue's Santa Trinità *Madonna*, and for this reason it was rightly honoured over the centuries. It exhibits all the lyrical qualities of Duccio's later work, the *Maestà*. If Cimabue's San Domenico Arezzo *Crucifix* shows signs of all the harsh lessons of Dominican sympathies, as symbolic of what Chiellini (1998:8) calls the "rational and hierarchical clarity of divine thought," then the Rucellai *Madonna* is the opposite. Despite being a Dominican commission, and being created by an artist with obvious Dominican allegiances, it is prettier and softer even than the Santa Trinità *Madonna*. The Rucellai *Madonna* is certainly a painting with a heart, and its subtle beauty appealed to the Florentine imagination over the centuries.

By comparison Cimabue's San Domenico Arezzo *Crucifix* is more in keeping with the harsher precepts of Dominicanism. The San Domenico Arezzo *Crucifix* seems to concentrate every fibre of the suffering body, so that the viewer is more aware of Christ's anguish than of His sacrifice. This depiction softens markedly when Cimabue, some ten to fifteen years later, reworks the same figure into the Santa Croce *Crucifix*, this time for the Franciscans. Chiellini notes the differences.

Within a traditional composition, similar to the one he had used in Arezzo, the artist here [in the Santa Croce *Crucifix*] introduces a number of variations, making his portrayal of Christ more human, less regal and sumptuous. If we compare it with the Arezzo *Crucifix*, the proportioning of the figure is less rigid and the curvature of the body is more striking, for it reaches the edge of the ornamental background; the figure's arms are clearly being pulled and stretched by the weight of the body, which appears to be much more realistically inert and lifeless (Chiellini 1998:15).

The San Domenico Arezzo *Crucifix* therefore remained marginalised as an artwork, and only recently began to enjoy a new prominence in the art historical canon of thirteenth-century Italian painting. A decisive attribution to Cimabue was first made only recently, in 1927, by an Italian scholar Pietro Toesca (Maetzke 2001:27), and even then he saw it as a pinnacle of the Italo-Byzantine style rather than as a herald of something new. Even today, although some scholars admit a "new vitality" in the San Domenico Arezzo *Crucifix* they nevertheless see it as still "strictly bound to Byzantine prototypes" (Maetzke 2001:26–27). Yet these are the same scholars who were later left speechless by the proficiency of the under drawing revealed by infrared reflectography.

The uneasy history between Florence and Siena, and the constant struggle for dominance in the Church between the Franciscans and the Dominicans, has had the effect of polarising the memory and contributions of Cimabue and Duccio. Cimabue was a decorator and painter of mainly Franciscan commissions. That he likely owed his novel style to Dominican research and fervour has not previously been clear without the benefits of this current optical research. Duccio, on the other hand, was a Dominican artist. Yet, the Florentine and Sieneese must have, at some stage, worked together, as Bologna strongly surmised.

Thus the view that Duccio as a young man was a pupil of Cimabue, and especially that he worked with him on the Assisi frescoes (as well as the Castelfiorentino *Madonna*), is seen once more to be defensive in exactly the terms that recent studies purported to refute (Bologna 1983:338).

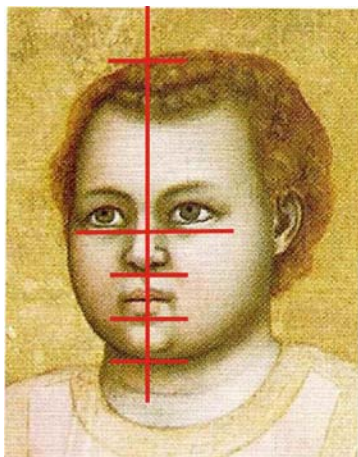
More significant, perhaps, is the strong stylistic relationship that can be established between the two artists' works in terms of the opticality of their artistic inventions.

3.1.2 The Madonnas of the Uffizi

Three relatively famous large medieval Italian altarpieces hang together in the second hall of the Uffizi Gallery in Florence (www.uffizi.com). Duccio's Rucellai *Madonna* was moved from the Church of Santa Maria Novella to the Uffizi in 1948, and was restored between 1988 and 1989 (Maginnis 1994:151). Cimabue's Santa Trinità *Madonna* has been in the Uffizi since 1919, and was restored in 1993 (www.virtualuffizi.com). Also in 1919 the Uffizi acquired

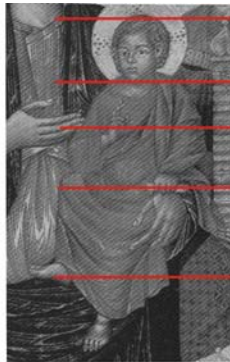
Giotto's Ognissanti *Madonna*, which had been painted for the high altar of the Church of Ognissanti, Florence, around 1310 (www.virtualuffizi.com). Together these art works offer an interesting comparison for optical analysis.

The portrait of the Rucellai Christ child and the portrait of the Santa Trinità Christ child could both have been created using an image projection. They are accurate to recognised proportions of a child's facial structure. Further, a child's head is small enough that it could have been projected at a 1:1 ratio, that is, a magnification of 1, using a very simple biconvex lens system (see exp 2). The child portrait of the Ognissanti *Madonna* is, on the other hand, clearly out of proportion (exp 24). The chin is large and the eyes are too high in the head. The portrait lacks the large forehead noted in a child's anatomy. The child's portrait in the Ognissanti *Madonna* was unlikely to have been created using an optical projection of a real child, as it does not demonstrate accurate standard facial proportions, as one would expect. As a consequence, Giotto's portrait of a child looks more like the medieval Italo-Byzantine scaled-down adult.



Experiment 24. Figure showing the facial proportions of the Christ child from the Ognissanti *Madonna*.

Nevertheless, Giotto has applied some childlike proportions to the figure as a whole. For example, the child's arms, although still too long for a small child, are not as long as depicted on some earlier examples, such as the Sienese *Madonna of the Large Eyes* and the Bigallo Master's *Madonna*, where the children's arms are as long as an adult's arms. The child's hands and feet are chubby in presentation, like those of the Christ child figure of the earlier Cimabue altarpiece. Cimabue's attention to an average child's anatomy indicates that he had begun to look more carefully at the differences between an adult's anatomy and that of a child, and to treat children not only as children, but also as individuals. In the Santa Trinità *Madonna* he has shown the child's eyes as large and bright, and has paid particular attention to anatomical detail such as a suggestion of tear ducts, and the placement of the irises, the one closer to the viewer being larger and the one further away being smaller. The nose and ears are cute and small. The left hand clutching the scroll is chubby like a child's, although the right hand raised to bless is more formal and adult. The hair is crafted in attention to its own style, with individual waves, curls and strands. The extreme accuracy and detail of the children's portraits on both the Rucellai *Madonna* and the Santa Trinità *Madonna* suggests that these two portraits were probably optical inventions, whereas Giotto's later portrait, with its idiosyncratic abstract anomalies, strays quite far from an optical accuracy. It is a careful portrait, but not as convincingly individualistic (exp 25).



Experiment 25. Images comparing and contrasting the drawing logic in the Santa Trinità *Madonna*, the Rucellai *Madonna* and the Ognissanti *Madonna*.

The artistic observation of outline is most advanced in the Rucellai *Madonna*, although areas of the Ognissanti *Madonna* do show an attention to outline, such as in the hem of the skirt and the detail of the raised right hand. The use of negative space is most subtly displayed in the Santa Trinità *Madonna*, while the Ognissanti *Madonna* shows an almost sculptural solidity, an isolation of form rather than an integration of shape into background and foreground detail. The overall proportions of the three child images are relatively similar, with all showing arms and legs that are relatively too long. Exceptionally, however, in the Ognissanti *Madonna* it becomes clear that although the head is relatively well described, the facial features are really too big, that is, they take up too much space, and therefore render the portrait adult looking. Finally, the light logic in the Rucellai *Madonna* is the most advanced and perceptively defined, with areas of light grading subtly into areas of dark, perfectly rendering the soft features of a child. On the other hand, the artist of the Ognissanti *Madonna* uses highlights flatly, and shadows serve the function of outlining shape and form. The drawing Gestalt can therefore be stated as being the most advanced in the Rucellai *Madonna*, which shows a finely observed and acutely accurate portrait of a small child.

The pose of the Christ child in Giotto's Ognissanti *Madonna* is also much more formal, echoing the stiff pose of the frontally placed traditional Christ-child figure. On the other hand, in both the Rucellai *Madonna* and the Santa Trinità *Madonna* subtle body placements make these Christ-child figures much more lifelike. They have begun to wriggle in ways a child might, suggesting a

closer observation of the child model, perhaps under a light projection. For example, in the *Santa Trinità Madonna* the child's right foot sneaks up into the Madonna's cape, and in the *Rucellai Madonna* the child's left leg is pulled up casually into the body. Further, the child's right arm (the arm traditionally raised in blessing) in the *Rucellai Madonna* is less contrived than even in the *Santa Trinità Madonna*. Although the index and middle fingers are represented in blessing, the hand also functions in a resourceful way that makes it seem as if the child is reaching for the mother's cape. This echoes the placement of the Christ child's arm in Cimabue's *Assisi Madonna and Child Enthroned*.

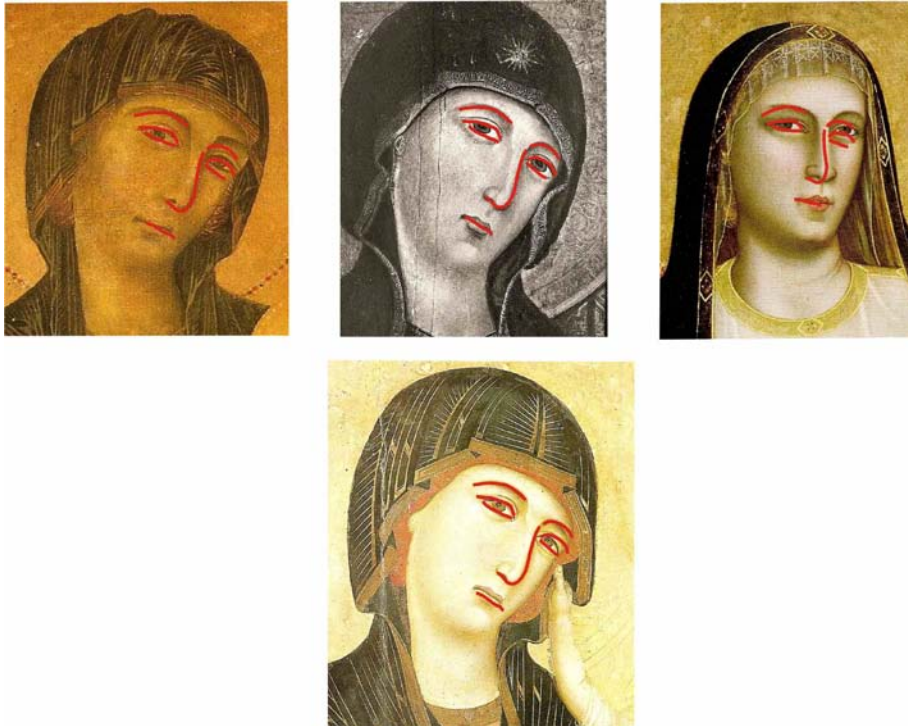
This humanisation of the relationship between the Madonna and her child was not, it would seem, without precedent, particularly in sculpture, as White points out.

An affectionate interaction between mother and child is already well established by the middle of the century in French and English miniature painting, as well as in Italian panels, and the increasingly subtle humanizations of their relationship is fundamental not only to the art of Nicola Pisano but, above all, to that of his son Giovanni (White 1979:23–23).⁶

Nevertheless, it can be stated that the altarpieces of *Rucellai* and *Santa Trinità* inspired a new trend in Italian painting, in the individual gestures of the Holy unit. From regularly following a set strict formula for the depiction of the Madonna and child, artists began to explore a new concept of relationship, such as in the *Crevole Madonna* (c.1285, plate 22) and the *Castelfiorentino Madonna* (c.1285, plate 23).⁷

However, even in later altarpieces depictions of the Madonna's facial features seem to remain relatively formulaic, that is, in the Italo-Byzantine style. The *Santa Trinità Madonna*, the *Rucellai Madonna* and the *Crevole*

Madonna are all closely related (exp 26). The Ognissanti *Madonna* follows this formula to an extent, but also shows some differences, for example, in the nose, which is presented in more naturalistic detail, and in the mouth, which is more convincingly shown from a three-quarter view. Even so, Giotto's Ognissanti *Madonna* is less realistic, in terms of proportions, than Duccio's Rucellai *Madonna* (exp 27). In the Ognissanti *Madonna* the Madonna's eyes are placed too high, as are the nose and mouth, and the portrait cannot, therefore, be considered realistic in terms of standard anatomical facial proportioning. On the other hand, Duccio has placed the eyes, nose and mouth more accurately. Nevertheless, although the Rucellai Christ child seems more real than the Ognissanti Christ child, overall the Ognissanti *Madonna* is more solid and earthly, more tending towards a pre-Renaissance conception of the "modern." The relationship between Duccio's individualistic approach, marked in the Rucellai *Madonna* particularly by the lively and believable portrait of the child, and Giotto's more earthly and monumental naturalism, as seen in the figure of the Madonna, must be explained.



Experiment 26. A comparison of the main facial features of the Madonna using the Rucellai *Madonna* (centre) as a control. In comparison are the Santa Trinità *Madonna* (left), the Ognissanti *Madonna* (right) and the Crevole *Madonna* (bottom).



Experiment 27. A comparison of the main facial proportions of the Madonnas in the Rucellai *Madonna* and the Ognissanti *Madonna*

3.2 DUCCIO AND GIOTTO

As has been shown in relation to the Ognissanti *Madonna*, Giotto's painting cannot be considered exceptionally individualistic, as it lacks the standards associated with an optical invention. The Ognissanti *Madonna* does not show the same attention to the four sets of drawing skills defined by Edwards and Bomeisler, and identified in both Cimabue's San Domenico Arezzo *Crucifix* and Duccio's Rucellai *Madonna*. The Gestalt of an individualistic *disegno*, as identified by Edwards and Bomeisler, is missing in the Ognissanti *Madonna*. This is clearly antithetical to Vasari's opinion – an opinion which has been regurgitated throughout the centuries – that it was Giotto who was the inventor of “naturalism” in Italian painting towards the end of the Trecento. Vasari states that Giotto was “so good an imitator of nature that he banished completely the rude Greek manner and revived the modern and good art of painting, introducing the portraying well from nature of living people, which had not been used for two hundred years” (translated and quoted in Maginnis 1993:386). This is clearly a false assumption. It was models like Cimabue's figure of Christ crucified on the San Domenico Arezzo *Crucifix*, and the Christ child portrait study from Duccio's Rucellai *Madonna*, which set the early standards of portraying individual three-dimensional objects on a two-dimensional plane in a way that was close to the proportions of nature, and to the concept of solid objects depicted in terms of light and shadow. The guide for this individual way of looking at nature was the image projection.

The claimed primacy in Giotto's work of a new type of individualistic expression in narrative scenes is also somewhat false. For example, Albert Bush-Brown states that Giotto originated the concept of activity in painting.

Giotto invented several powerful methods to ensure visualization of a more natural space and more natural figures. Two of these innovations, emotionally as well as spatially effective, occur in the *Pietà* [plate 24]. So far as we know, this is the first scene in the history of painting which has a figure gesticulating as John does here, a pose which is remarkable among Giotto figures for its strong elements of contortion. The other great dramatic innovation is that of the two anonymous women whose shapeless, mourning backs alone are presented as a barrier in front of the main figures, a magnificent departure from previous, traditional inscenation which displayed the main scene immediately with the figures generally in frontal poses (Bush-Brown 1952:42).

In fact, Duccio preceded Giotto in both these supposed innovations, that is, in the presentation of a strong contortion of the figure into an expressive pose, and in the placing of a figure with the back to the picture plane. In the *Crucifixion with Sts Nicholas and Gregory* he depicts a figure with one hand on the hilt of his sword, and the other arm flung into the air in a gesture of hopeless pain and horror. Another figure sits in the bottom-right corner of the picture plane, with a hand held up and the torso twisted around so that the back is turned to the viewer. To the left Mary slumps into the arms of the surrounding women in absolute grief and dejection. Giotto's fresco of the *Pietà* (c.1303–1305), in the Scrovegni Chapel in Padua is dated after Duccio's so-called *Boston Triptych* of the *Crucifixion of Sts Nicholas and Gregory* (1300). However, the *Boston Triptych* is a small wood panel, with the central figure of Christ barely filling the size of an A-3 page, whereas Giotto's *Pietà* is a fresco of large dimensions. For this reason, it may be that the earlier work of Duccio has been overlooked.

Influence presupposes some sort of contact, yet it is highly unlikely that Duccio ever travelled to Padua, near Venice, or even that he was particularly aware of Giotto's frescoes there. On the other hand, Giotto was a Tuscan, like Duccio, and would have had much easier access to Duccio's work, including the Rucellai *Madonna* in the Church of Santa Maria Novella, in Florence. An earlier fresco cycle attributed to Giotto, found in the Upper Church of the Basilica of St Francis in Assisi and dated to around 1290, is much more formal and restrained than the Paduan cycle, as are various other panel pieces attributed to him from around 1300 (Zuffi 2006:64–128). It is only after Duccio's own innovative departure from the frontally schematic narratives of the Trecento that Giotto begins to explore this same expressionism in his painting. Furthermore, Duccio can also hardly have been influenced by Giotto in the preparation and presentation of his own narrative scenes for the *Maestà* (1308–c.1311, plate 28), which was designed for the Duomo in Siena (now in the Museo dell'Opera del Duomo).

The key to this dilemma may lie in a crucifix in the Church of Santa Maria Novella (c.1299–1303, plate 25), which for many centuries has been attributed to Giotto. Bruce Cole waxes lyrical about what he sees as Giotto's advanced realism in this particular crucifix.

High up on the entrance wall of the sacristy of the Dominican church of Santa Maria Novella in Florence is a large and very beautiful *Crucifix* by Giotto, one of the artist's first known works – c. 1299–1300. A comparison of it with Cimabue's Santa Croce *Crucifix* reveals the former's importance for the history of Florentine art. The basic conception of the two Christ figures is strikingly different. Cimabue's, although more naturalistic than anything produced up to the time, seems symbolic when compared with the stark realism of Giotto's, where the vestiges of the old abstraction have been done away with and the spectator is confronted with the awesome image of a dead, greenish

Christ hanging from a cross. No longer does the figure share the majestic iconic conception of even the last of Cimabue's Christs. The remote, heroic Son of God has been replaced by a very human image of a dead man divested of all the old associations of hierarchical grandeur which date back to the very beginning of Florentine art. Here is the first fully realistic portrayal of Christ in the history of Western painting (Cole 1976:40).

Cole is both absolutely right about this crucifix, and also absolutely wrong. The common assumptions he makes about this very crucifix are crucial to an understanding of how optics were employed (or not) by medieval Italian artists, specifically the Tuscans, around the beginning of the Trecento.

The attribution of this crucifix to Giotto is far from solid. As Cole himself points out, the crucifix does not sit easily with the style of Giotto's later work (Cole 1976:179).

In that year [1312] a Florentine named Riccuccio di Pucci left money for a lamp to be lit in front of a cross by Giotto [in the Church of Santa Maria Novella]. According to the terms of the legacy of the same Riccuccio, three years later a lay confraternity paid for an ounce of oil for the lamp in front of a cross by Giotto (Cole 1976:179).

It could be that this document led later authors to believe that this crucifix is indeed one by Giotto. Certainly, the idea of a crucifix by Giotto in Santa Maria Novella is also mentioned by Antonio Billi in the 1500s, as well as in an anonymous manuscript in the Biblioteca Nazionale in Florence (Cole 1976:180). Lorenzo Ghiberti also referred to a crucifix by Giotto in Santa Maria Novella (Zuffi 2006:110), as did Vasari (Cole 1976:180). "In the eighteenth century Domenico Manni copied from the archives of the church part of a document stating that Giotto finished a cross in 1312" (Cole 1976:179). Zuffi's notion that the crucifix can be associated with Giotto's frescoes in the Upper Church of the Basilica of St Francis in Assisi (Zuffi

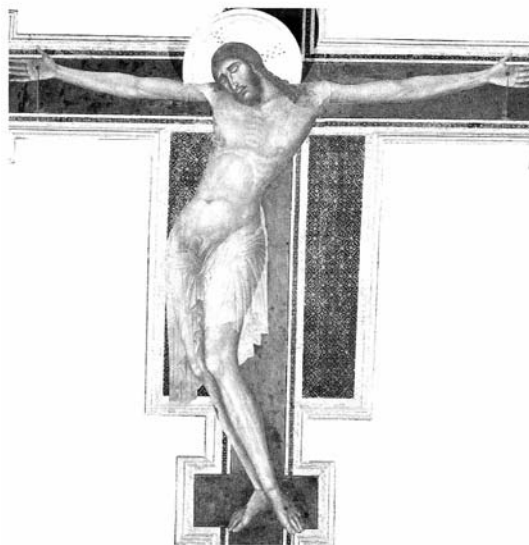
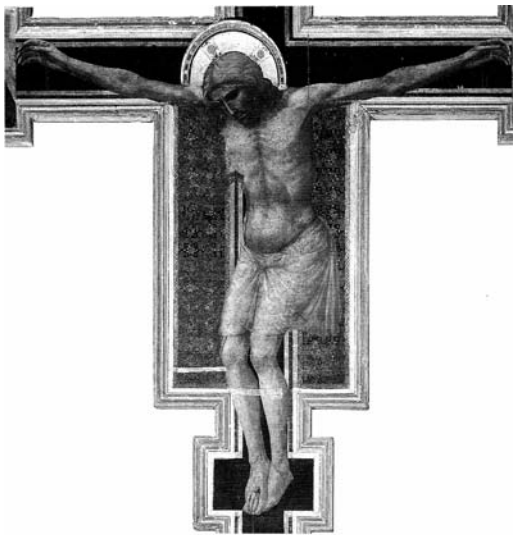
2006:110) is something of a stretch of the imagination, and the number of authors who consider this crucifix autograph does not really inspire confidence. After all, many were wrong about the Rucellai *Madonna*, originally in this very same Dominican church in Florence.

Both Zuffi (2006:10) and Cole consider this crucifix to have left behind all the iconic restraints of the Italo-Byzantine style, which can still be identified in crosses such as Cimabue's San Domenico Arezzo *Crucifix* and Santa Croce *Crucifix*. Zuffi states that Giotto "has abandoned every typical hieratical reference to the art of the Byzantine and, moreover, has surpassed the new style elaborated by Giunta Pisano and Cimabue" (my translation) (Zuffi 2006:110).⁸ Cole cites certain formal stylistic qualities which he sees as marking this crucifix as a significant step in the medieval Italian invention of naturalism.

The use of light and shade to shape highlights and shadow has also undergone a drastic change. No longer is the broad, almost decorative use of highlighting seen. The modulation of light and dark over the surface is much more gradual, more naturalistic. Areas are fleshed out and made to appear real through a delicate, totally understood use of light. A good example of the difference between the two works [that is, Cimabue's Santa Croce *Crucifix* and this Santa Maria Novella *Crucifix*] may be seen by comparing the use of light on the chest and legs. This change from a more abstracted, decorative use of light to a manner that corresponds closely to what we see around us implies vastly different ways of visualizing and recording the world (Cole 1976:43).

It must be considered, however, that to say that Cimabue used highlighting in a purely decorative way is untrue. Diagnostic tests show that Cimabue already used an intelligent light logic as early as the San Domenico Arezzo *Crucifix* (c.1275). He translates this light logic into a more graded form in the Santa Croce *Crucifix* (exp 28), although his highlights remain much brighter than

those found on the figure of Christ on the crucifix in Santa Maria Novella. In reality there is a harmonious equivalence between the light logic in the Santa Maria Novella *Crucifix* and the Santa Croce *Crucifix*. The light logic in the Santa Maria Novella *Crucifix* builds on the lessons of the Santa Croce *Crucifix*, it does not deny it. In fact, the Santa Maria Novella *Crucifix* is a natural progression from Cimabue's San Domenico Arezzo *Crucifix*, San Domenico Bologna *Crucifix*, and Santa Croce *Crucifix*.



Experiment 28. Figures manipulated to enhance "light logic" in the Santa Maria Novella *Crucifix* and in the Santa Croce *Crucifix*.

The Santa Maria Novella *Crucifix* is very closely related to the crucifix on Duccio's *Boston Triptych* and to Duccio's crucifix on the *Maestà* (plate 28(ii)). Using certain optical analyses (exp 29) it can be stated that the crucifix on the *Boston Triptych* is likely the original invention, making its attribution to Duccio quite certain, despite some scholars' past reticence to ascribe it so (Arb 1959). The figure of Christ from the *Boston Triptych* is significantly elongated in comparison to the crucifixion scene from the *Maestà*, so that the feet of the *Maestà* Christ figure are placed relatively higher. Nevertheless, the arms fit, and the basic shape and hang of the body is equal. However, rotating the image back using the **3-D Rotation Tool** set at 10° affords an almost perfect fit between the figure of Christ in the *Boston Triptych* and the figure of Christ crucified from the *Maestà*.

The idea of using a perspective tool to realign the figure of Christ from the *Boston Triptych* with the figure of Christ from the *Maestà* is born of research which shows that artists using projected images can inadvertently stretch out the real image by placing the receiving support at an inclined angle to the hole (see exp 30). Therefore, having observed that the figure of Christ on the *Boston Triptych* was elongated in comparison to the figure of Christ on the *Maestà*, I came to the conclusion that the reason for this was an optical distortion. That this distortion can be corrected using computer technology is clear evidence of a primary optical invention, and suggests that the artist seems to have used the natural phenomenon of image projections in a way like an ancient photocopier, in other words, he seems to have placed the existing

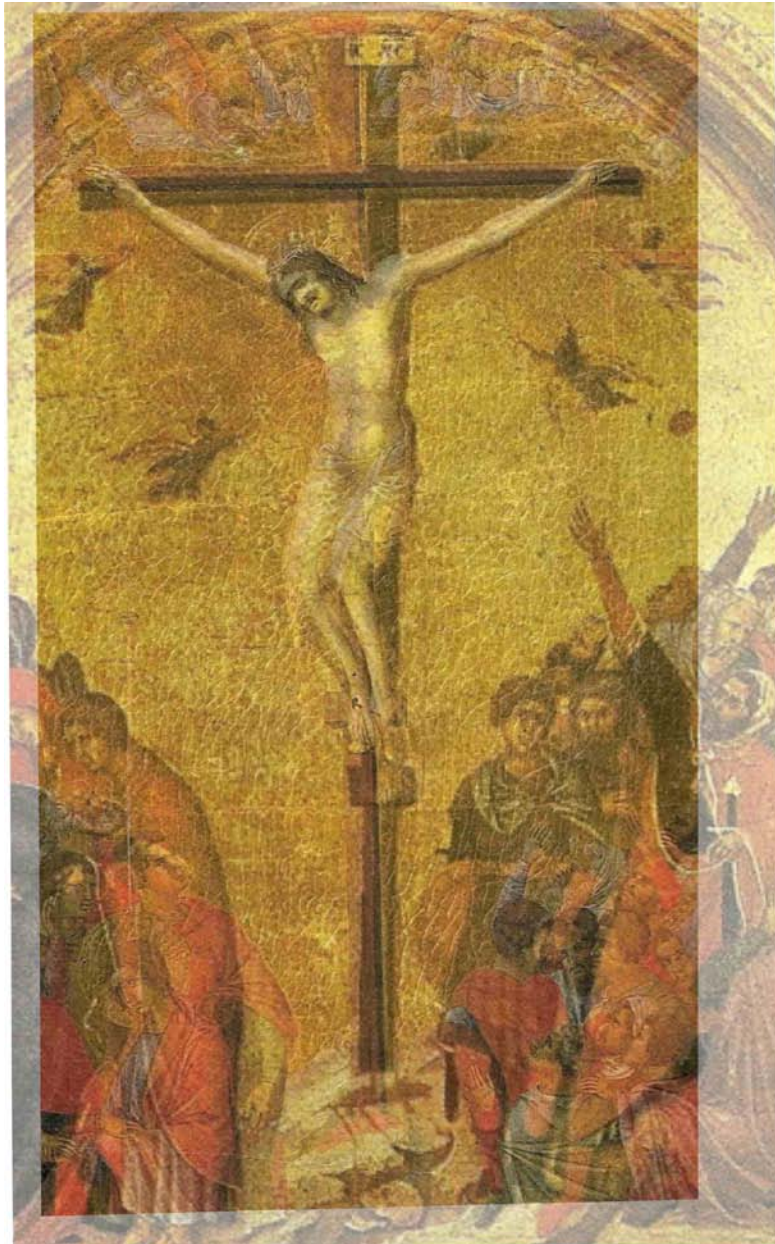
artwork (undoubtedly the *Boston Triptych*) in the sunlight and projected the image onto a support inside the dark room, the effect being to readjust the original distortion (fig 15). That the artist was able to alter the elongation by any other mechanical means is unlikely. This echoes Witelo's proposal that such a setup was a mechanical possibility.

Take a convex cylindrical mirror, ... [and] Let it be stood upright on its pedestal, somewhere in a suitably spacious house, ... Let a board, with a painting somewhere on it, be arranged on this line outside the wall, so that the middle of the picture painted on the board is placed on [the imaginary] line ..., and is positioned in such a way that the picture on the board cannot be seen from the existing line of vision at point *n* or near it. Nevertheless, with visibility so arranged, the image of the picture will be seen reflected in the air from the surface of the cylindrical mirror (translated and quoted in Hockney 2001:206).⁹

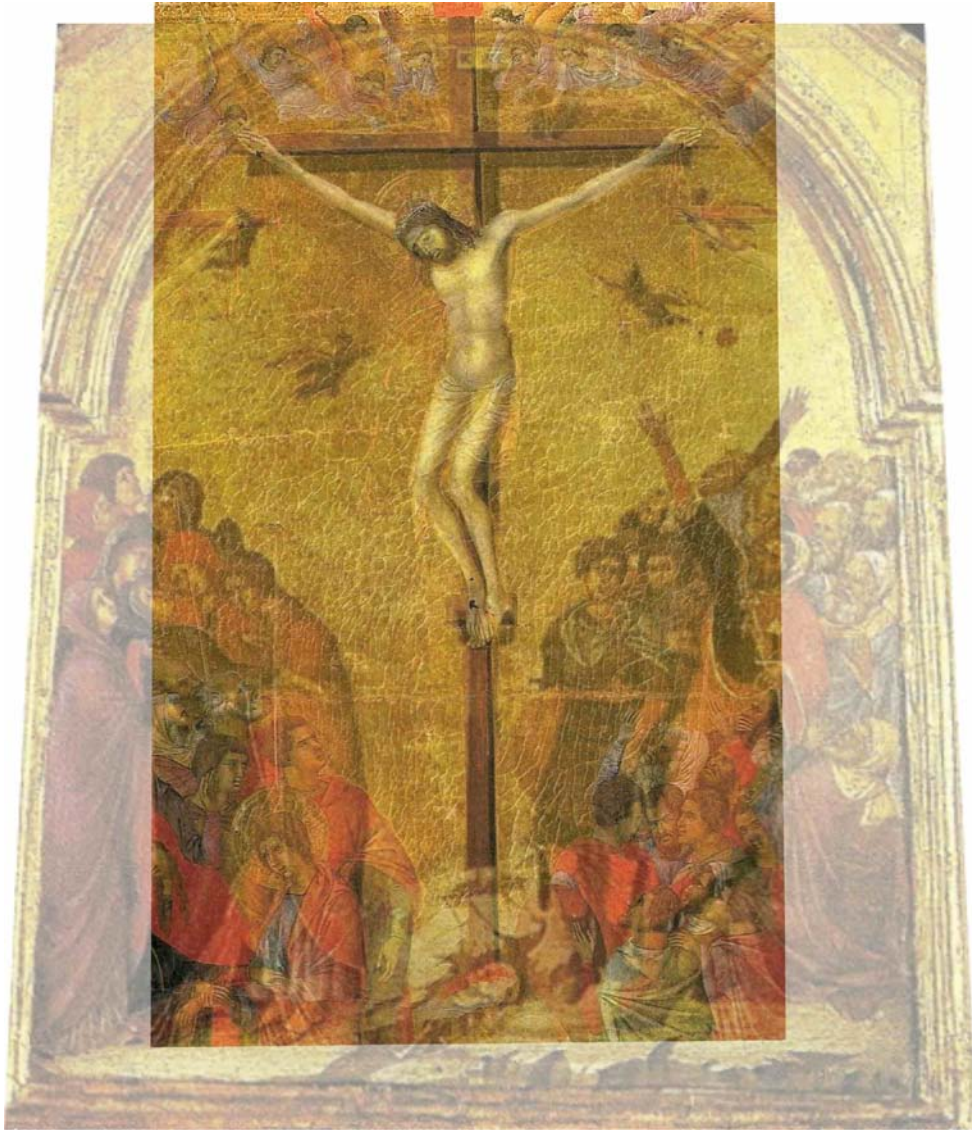
Hockney states that substituting "a concave mirror for a convex-cylindrical mirror in Witelo's description ... [will match a] mirror-lens set-up exactly" (Hockney 2001:206).

The figure of Christ from the *Boston Triptych* and the figure of Christ from the *Maestà Crucifixion* are so closely related that one is a direct copy of the other, adjusted on the vertical. In all probability Duccio used a projection method to copy the *Boston Triptych* figure over onto the *Maestà* panel at a magnification of 1. Hockney (2001:78) calls this way of projecting a flat image (like a previously executed panel) an "epidiascope." Although the placement and sway of the figure is imitated in the Santa Maria Novella *Crucifix*, the many differences between the two poses suggest that the Santa Maria Novella *Crucifix* was observed from a different model, and is, therefore, a new invention. The arms are placed much higher in the *Boston Triptych*, and the buttocks juts out more to the model's left in the Santa Maria Novella *Crucifix*, having the effect of bringing the knees more tightly in line with the vertical.

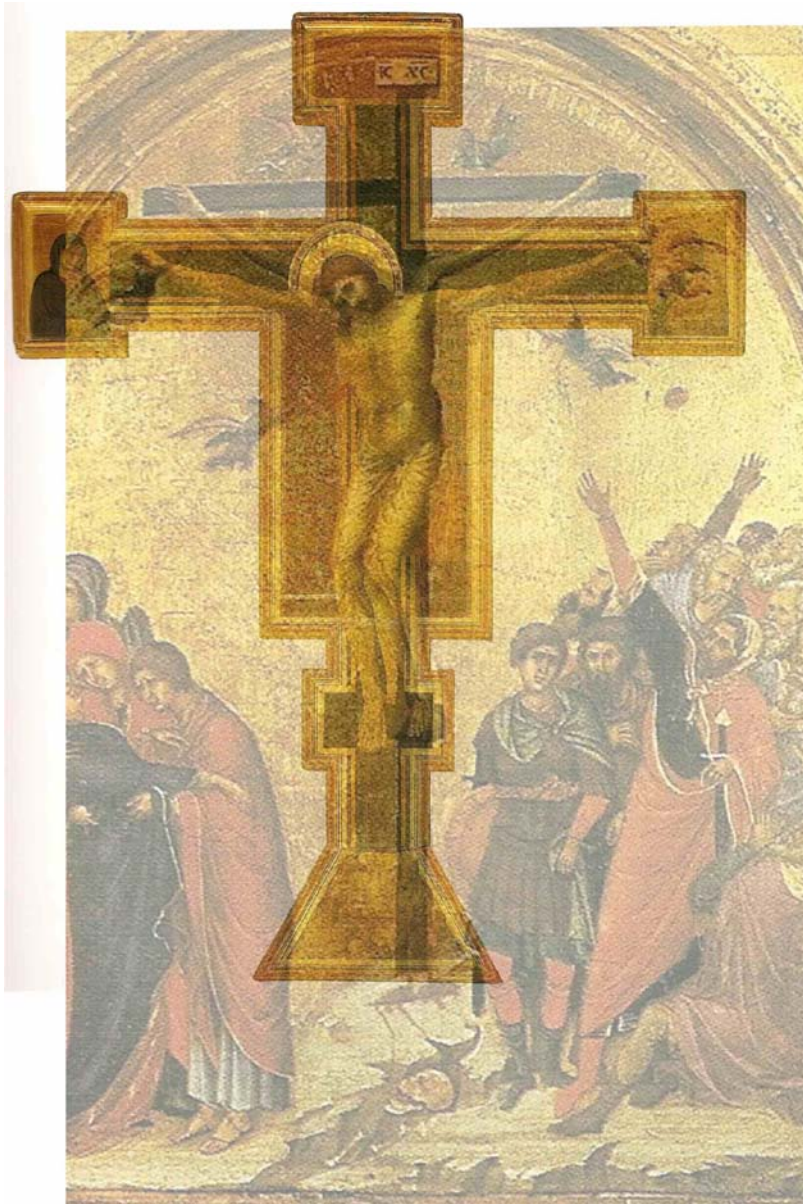
Nevertheless, the close association in style and iconography suggests that the artist of the *Boston Triptych* and the *Maestà* was the same artist who executed the Santa Maria Novella *Crucifix*, that is, Duccio di Buoninsegna. Further evidence is in the physiognomy of *St John* from the wing of the Santa Maria Novella *Crucifix*, which is closely similar to the physiognomy of *St John* in the crucifixion scene of the *Maestà*. The model has the same long, hooked nose, the same deep set dark eyes, the same shaped mouth, the same intense expression and the same curly auburn hair. The artist has used the outline of *St John* to create the figure of *St Mary* on the Santa Maria Novella *Crucifix*, creating a man-woman in the same way that Cimabue did on the San Domenico Arezzo *Crucifix*.



Experiment 29a. A transparency overlay shows that, although very closely associated, the figure of Christ from the *Boston Triptych* is elongated in respect to the figure of Christ from the *Maestà*.



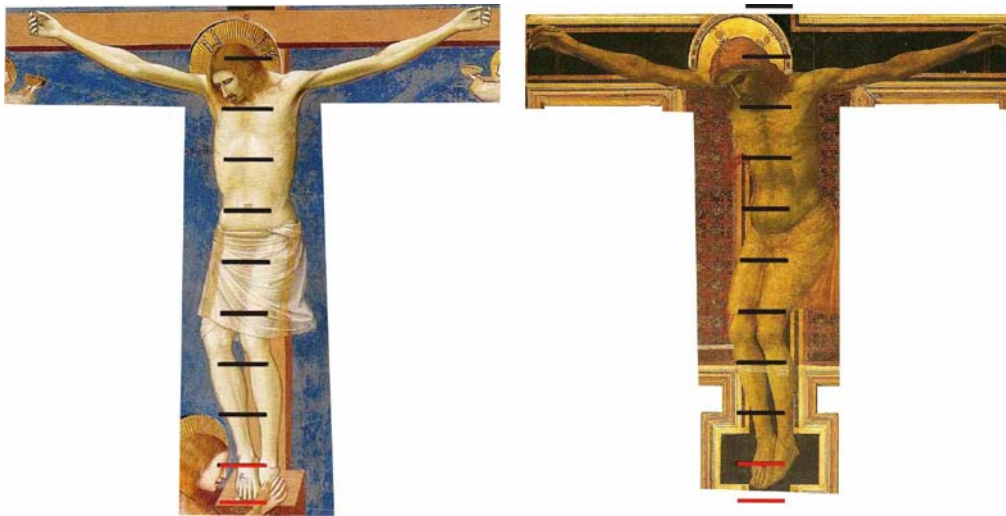
Experiment 29b. By first rotating the image of the *Boston Triptych* by 10° a transparency overlay of the figure of Christ from the *Boston Triptych* fits very closely with the figure of Christ from the *Crucifixion* scene in Duccio's *Maestà*.



Experiment 29c. A transparency overlay shows that, although closely associated, the figure of Christ from the *Boston Triptych* shows certain differences, relating to pose, to the figure of Christ from the *Santa Maria Novella Crucifix*.

Of course, if Giotto had been the artist of the *Santa Maria Novella Crucifix*, he could have imitated Duccio's small crucifixion scene from the *Boston Triptych*. However, one can easily reject this supposition on a number of grounds. The treatment of cloth in the portraits of *St John* and *St Mary* in the *Santa Maria Novella Crucifix* is quite different to Giotto's preferred taut

monumentality as seen in the Padua fresco cycle, where the figures are seemingly swathed in solid marble. The artist of the Santa Maria Novella *Crucifix* treats the folds of cloth in a more cursory and painterly fashion. The figure of Christ crucified in Giotto's Paduan fresco cycle (plate 26) also lacks in elements of an absolutely accurate and realistic proportioning (exp 31).



Experiment 31. Graded markings showing proportions on the figure of Christ from Giotto's Paduan fresco cycle and the figure of Christ from the Santa Maria Novella *Crucifix*.

The commission for the Santa Maria Novella *Crucifix* came from the Dominican brothers and is in the same Church where Duccio's Rucellai *Madonna* was originally found hanging. It shares many stylistic and iconographic similarities with other work by Duccio at this time. On the other hand, it is not convincingly in a style that can easily be associated with Giotto. At the turn of the century, Duccio was an established artist, with clear Dominican sympathies. Giotto was an unknown. It is not even clear where he came from and why he turned to painting at a relatively late age,¹⁰ but it would seem that his artistic roots were in sculpture. Lorenzo Ghiberti (1378–1455)

seems to have been the source of the legend that had Cimabue “discover” the young Giotto, sketching goats and sheep on rocks in his father’s fields in Vespignano (Eimerl 1967:82). Vasari embroidered this tale in his *Lives of artists*, and Leonardo repeated it in his *Codex Atlanticus* (Eimerl 1967:82). I believe this legend may be a hidden clue to Giotto’s true beginning, that is, as a sculptor, which was why he was drawing on rock, and not in the sand, for example. For some reason, like the later Michelangelo, he turned to painting mainly frescoes, and also took on an architectural project in his twilight years, the famous Bell Tower in Florence (Eimerl 1967:159).

Around the turn of the century Giotto may well have taken note of Duccio’s work, and would probably have known about him through his contacts with the Pisani, father and son sculptors. Nicola Pisano (c.1220–1284) designed and executed the pulpit for Siena Cathedral in 1268 (White 1979:100), and his son Giovanni Pisano (c.1250–c.1315) was asked to decorate the façade (White 1979:101). Duccio’s *Maestà* was commissioned for the altar of Siena Cathedral in October 1308 (White 1979:80), and Duccio borrowed certain motifs from the Pisani, such as the king kneeling with his crown hanging around his arm, seen in the *Adoration* scene from the front predella (White 1979:125). However, Giotto, much more than Duccio, was heavily influenced by the sculptural style of the Pisani, and there are many strong parallels between his painting and their relief work.

Giotto, in his *Pietà*, develops this new [Latin] visualization; although it is impossible to say in the narrow sense that the Pisani were his models, the spatial device is potentially there. Giotto turns what is almost accidental in quality in the pulpits into a monumental visual principle. He dramatizes the figures, makes them larger and more monumental, changes their rhythms, and he sees the whole scene from a lower and

more unified point of view so that the hulking, seated figures [with their backs to the viewer] obscure what is behind them. Indeed, the figures and spatial development have undergone those stylistic transformations which we noted earlier in respect to the figures of [Nicola's] Joseph and Giotto's Joachim, but the inspiration for the developed form seems to lie in the work of the Pisani (Bush-Brown 1952:46).

Further, Giotto's Ognissanti *Madonna* closely resembles the style and form of a sculpture of the *Virgin and Child* (c.1299, plate 27) by Arnolfo di Cambio (c.1240–1302), who was a pupil of Nicola Pisano (Cole 1976:36).

Duccio and Giotto are at the very root of the dichotomous nature of later Italian Renaissance painting, which is divided into the anecdotal school of colour and the school of shape. What I show is that at the very beginning of so-called "naturalism" was the artist Cimabue, learning from the projected image and passing these lessons on to Duccio. Giotto, who appears to already understand the tactile nature of form, learns about painting from Duccio, but brings with him, it is my conjecture, a solidness from his three-dimensional training in sculpture. Giotto is the forefather of monumental Italian naturalism, the herald of later artists such as Massacio (1401–1428) and Michelangelo (1475–1564). His art is more universal. On the other hand, Duccio, the gentle colourist and faithful reporter of human activity, is the herald of later artists such as Giorgione (c1477–1510), Titian (Tiziano Vecellio, c.1490-1576) and Leonardo. His art is more individual. The pinnacle of Duccio's achievement is his *Maestà*, which I will now turn to in more detail.

3.3 DUCCIO'S *MAESTÀ*

3.3.1 The narrative of a new style

The *Maestà* was one of the largest Italian altarpieces ever commissioned. Originally it was just under five metres high and five metres wide, and was painted on both sides (Bellosi 1999:9). It seemed to follow a commission in 1302 for another panel *Maestà*, which was placed in the chapel of the Palazzo Pubblico for the elected ruling body of Siena, the so-called Nine, but is now lost. The original contract for the commissioning of the Siena Cathedral *Maestà*, dated 9 October 1308, still exists (White 1979:18). In 1771 the *Maestà* was sawn down the middle, and broken up into different pieces (Bellosi 1999:12). In 1878 it was moved from Siena Cathedral to the Museo dell'Opera del Duomo (Bellosi 1999:12). Some of the panels were lost, and many turned up later in a number of modern museums, including the National Galleries of both London and Washington, and the Thyssen-Borne Collection of Lugano, now in Madrid (Bellosi 1999:12).

Notes to this section

¹ “Long before the present church was built there stood on this spot a small chapel called St. Mary in the Vineyard. This having been destroyed, the Dominicans, with the assistance of the Rucellai family, began the new St. Mary's in the year 1279. The design for the church was prepared by three Dominican friars, and is Italian Gothic, the shape being a Latin cross. The long nave is raised midway by one step, so that one seems to rise by slow degrees from the west door to the High Altar and to the group of chapels on either side of the choir.”

(http://numberonestars.com/travel/florence_santa_maria_novella.htm)

² The Rucellai *Madonna* is firmly dated to 1285, and many scholars favour a dating of around 1270 for the San Domenico Arezzo *Crucifix* (Bellosi 2001:17). Although I feel the work was done after Cimabue sojourned in Rome (1272), it was certainly executed after 1268 when the first knowledge of image projections reached Italy.

³ I am not suggesting that Cimabue knew of the Chinese sources of optics. However, it must be noted that European contact with Mongolian ruled Yuan Dynasty China was much more prevalent than is generally understood.

In 1264 Kublai Khan, grandson of Genghis, transferred his capital from Karakorum in Mongolia, to Beijing in north China (also Daidu – “great capital” and Peking). He adopted a dynastic Chinese title, Yüan (“great beginning”) in 1271, and made his focus a united China that included Mongolia, Manchuria and Tibet. (Buckley Ebrey 1996:172–73.) Trade and relations with Europe increased substantially, particularly with the Italian peninsula.

[I]n the middle of the thirteenth century it was Italy ... where international commerce was revived, which lay at the geographical centre of a network of trade routes radiating out from the Mediterranean, and also at the focal point of a system of currency and credit, and of business organization (Phillips 1998:96–7).

This period saw an intensification of east/west contact that had been reinitiated many decades previously. “[T]he extent of medieval European contacts with other continents was much greater and far more persistent than is generally realized” (Phillips 1998:vii). In 1279, a year after Duccio received his first known commission in Siena, the Southern Song dynasty in China finally collapsed under the rising pressure of Mongolian expansion. The whole of China was now under Mongolian rule. Europeans, especially the Italians, were quick to see the opportunities in travelling to places closed to them for a millennium (Phillips 1998:76).

⁴ There were many Tartar slaves in Italy at this time, and in 1287, for example, a Nestorian bishop from North China, Bar Sauma, made an historic visit to Italy. He is sometimes called “Marco Polo in Reverse” (Boser 2004:60).

⁵ St Catherine was famous for being instrumental in bringing the papal seat back to Italy from Avignon in 1377 ([Wikipedia Online Dictionary Sv. “Catherine of Siena.”](#))

⁶ The idea that early sculptors, even medieval ones, might have used optical projections has occurred to me on occasion. This warrants future research in an historical broadening of this thesis to include other art forms such as sculpture.

⁷ “Critics indeed are not unanimous even as regards the Castelfiorentino and Crevole Madonnas. White says nothing of the former work, but accepts without hesitation the general view that the second is a masterpiece by Duccio, some years earlier in date than the Rucellai Madonna. Stubblebine, on the other hand, denies the Crevole Madonna to Duccio and makes it the chief work of a Siennese painter in the style of Cimabue, who came under Duccio's influence from about 1285; while he attributes the Castelfiorentino Madonna to the earliest and most Cimabuesque period, between 1280 and 1285, of the ‘Master of Badia Isola’” (Bologna 1983:337).

⁸ One must recall here that the “Giunta Pisano” that Zuffi is referring to, I have reattributed to Cimabue, that being the San Domenico Bologna *Crucifix*.

⁹ The complete text of Witelo Lib.VII.Prop.60 is published in David Hockney's revised edition of *Secret Knowledge* (2006), and was supplied to me by David Graves (email 25 February 2006). “Take a convex cylindrical mirror, let it's line of axis be *abc*. Let it be stood upright on its pedestal, somewhere in a suitably spacious house, so that the line *ac*, centre point *b*, is upright over the floor of the house. Let a line be drawn cutting the mirror at point *b*, perpendicular to line *ab*, which shall be *dbe* which, following the line of points, *d* and *e* should

touch the walls of the house and these points should be marked on the walls. Therefore the surface on which line dbe lies, which is at right-angles to the axis of the mirror, clearly cuts through the mirror describing the curve.

Therefore above point d make a point f on the wall so it can easily be made closer still. Let a line be extended from point f which is equidistant from the line of the mirror, of whatever length you like, let this be gfh , centre-point f , and let the line fb be joined-up and extended through the wall to point k . Let the wall be cut through along line gfh , and on the other side of the wall, opposite the mirror, let the hole be made larger, just as is usual with the windows of a house. The cutting of the opening should follow the line bfk , and let the opening be fk .

From the point on the mirror which is b let a straight line be extended from the surface of the mirror, at an angle above line dbe which, extended beyond the mirror, shall be bm . Also, at point b , at the end of line bm and at the angle of kbm , let there be an equal angle which will be mbn when the line bn is drawn. Also, join the mirror to points g and h , which are the end-points of line gfh . Let them be ga and hc , which, extended, run together at point o . Let the line bo be drawn cutting the circular plane at b , and let there be a similar intersection for bn , so it may be equivalent to bo .

I say that if the centre of vision is placed at point n , to which is reflected the image of line gfh from the axis of the mirror, which is abc , the whole of line gfh will be seen, quite clearly, outside the mirror, between the mirror and the line gfh , and definitely close to point d on line de , which touches the mirror at point b .

If therefore, lines og and oh are extended through the wall to points p and q , and one line is joined, let that be pkq . Let a board, with a painting somewhere on it, be arranged on this line outside the wall, so that the middle of the picture painted on the board is placed on line pkq , and is positioned in such a way that the picture on the board cannot be seen from the existing line of vision at point n or near it. Nevertheless, with visibility so arranged, the image of the picture will be seen reflected in the air from the surface of the cylindrical mirror.

I seriously believe that in a similar way it is possible to set up pyramidal convex mirrors and the centre of vision. From spherical convex mirrors such a reliable image would not result as from the mirrors proposed. The proposition is complete. The eager enquirer following this method should be on his guard for in this current theorem which we have presented we have made use of this as an example so that by the circulation of Book Seven the way to seek knowledge of diverse skills may be open to the enquiring mind.”

¹⁰ Giotto was unheard of as a painter before the shaky attribution of the Santa Maria Novella *Crucifix* to him, dated around c.1300. His first really secure fresco commission was for the Scrovegni Chapel in Padua, dated c.1305. At this stage Giotto was nearly 40, but he could also have been nearly fifty if his birth date is pushed back to 1567 (Bologna 1983:339).

CONCLUSION

I have shown that medieval Italian artists could have used the projected image as a tool to create pictures that were different to the inherited style of the Italo-Byzantine tradition. The first artist to have the availability of this technology was probably the Florentine Cimabue, whose paintings show individuality as a key element. This individuality is evident in such paintings as his *San Domenico Arezzo Crucifix*, where the body of Christ has been exceptionally well defined in terms of frame, musculature and proportion, in comparison to the work of earlier artists where such definitions tended to be generalised and stylised. Yet the projected image provided much more than just a way of copying human proportions, suggesting lively narratives to Duccio and also inspiring artists to produce increasingly accurate urban scenes as in Duccio's *Temptation on the Temple*. Painting in Italy became more and more something that was a record of what is *seen*.

Chiellini (1988:28–29) notes, for example, the distinctive difference between Cimabue's depiction of Rome in the Assisi fresco evangelical spandrels, *St Mark and Italy* (c.1280–1283, plate 37), a city which he is recorded as having visited, and his other imaginary portrayals of Jerusalem, Corinth and Ephesus.

[T]he details of ... [Rome's] buildings are described according to varying degrees of precision, *as though each was seen at a different focus*. ... The realistic depiction of Rome is also topographically accurate, so that this fresco is quite different from the conventional images produced by the cartography of the period, which were either glorifications or wholly symbolic images of cities. This view of the city consists of a systematic study which becomes analytical in the depiction of details that allow us to identify the buildings with certainty (my italics) (Chiellini 1988:28–29).

Chiellini's description calls to mind reports of Roger Bacon's mapmaking skills. She singles out the most significant of Cimabue's Roman landmarks as the Castel Sant' Angelo (or Hadrian's Tomb), the Meta Romulus, the Vatican's St Peter's Basilica, St Peter's Belltower, the Senatorial Palace, the (now demolished) Capitol Tower, the Pantheon, and the Militia Tower, all of which she can recognise (Chiellini 1988:28–36). From the general angle of representation it seems Cimabue could have gained vantage of this choice of buildings from the top of a number of Rome's famous seven hills. What Chiellini does not suspect, however, is that Cimabue could have indeed 'focused' each landmark in turn, as he copied his urban subjects using a lens to make a collage of sample image projections.

It occurs to me, therefore, that in this thesis for the use of projected images in the creation of individuality in Italian painting from 1270, I am not so much as saying something entirely new, but rather taking a puzzle where a significant piece has always been missing and finishing it. From the time of Dante in the early fourteenth century there have been writers who observed that the Florentine Cimabue had that something extra. Vasari called this "the way and the features of the modern" (translated and quoted in Bull 1965:50), but it was never understood how this modernity was achieved. Twentieth-century art historians like Radke (1984) and Hills (1987) suspected there might be some connection between the flurry of optical interest in the Viterbo papacy, stimulated by the arrival of Roger Bacon's *Opus Majus*, and the new Italian painting of "pictorial space and pictorial light" (Hills 1987:3), but they did not find the camera obscura or image projections. David Hockney discovered the

camera obscura and image projections, but he did not go far enough back, in my opinion. Further, he did not show any convincing chain linking Shen Kua, *De Mirabile*, Roger Bacon and the development of naturalism in Western European painting, which I have. My thesis should also make a contribution to unravelling the medieval history of the camera obscura and knowledge of projected images, as called for by Needham in 1962, by realising that the letter *De Mirabile* was not written by Bacon but was received by him from a source in China, probably the Franciscan travelling monk Giovanni Carpini.

In much of the research into medieval painting which precedes my presentation of this thesis, many art historians identified a new approach to the study of light and space in medieval Italian painting, but they did not realise that this study was literal rather than theoretical. White (1979:13) talks about light and colour in Duccio, and Stubblebine (1973:190) finds Duccio to be the herald of a newfound attention to the realities of architecture and space, but neither realise that Duccio probably saw things differently because he had something different to see with, and that was an image projection. In keeping with early research I have not added any new artists or any new paintings to the picture of early naturalism, although I have given it a new name, that is, individualism. Nevertheless, I have shown that Cimabue's San Domenico Arezzo *Crucifix* is far more significant than has been previously given credit, and that it is equally as "modern" as his other work. Furthermore, I have made an extended contribution to recovering the work of the marginalised Duccio, but I acknowledge that this is not a process which was begun by me. Notably, optical theory has allowed me to clarify and reattribute an important crucifix to

this often neglected Sieneese artist. It seems to me that despite the reattribution of the Rucellai *Madonna* to Duccio no one thought to question the attribution of the important crucifix also originating in the same Church of Santa Maria Novella in Florence, probably because the standing attribution to Giotto is popular in a city where the artist is a local hero. In the same way, I have given back to Cimabue the obvious attribution of the central figure of Christ in the San Domenico Bologna *Crucifix*. It is perhaps somewhat startling that it went unnoticed just how exact this figure of Christ is to the Christ figures represented on the San Domenico Arezzo *Crucifix* and the Santa Croce *Crucifix*, and that it forms a mid-point between the two.

The experimental methodology that I have developed in the course of this thesis should make a contribution to the study of painting in general, not only to the study of those paintings which appear to have been optically conceived. This type of close analysis of the digitized image introduces a thoroughness that lacks in general art historical research, where images are studied in books or isolated in situ. The rigor of a computer-assisted analysis would have long ago cast doubts on the attribution of the San Domenico Bologna *Crucifix* to an artist different to the one who executed the San Domenico Arezzo *Crucifix* and the Santa Croce *Crucifix*, as the relationship between these crucifixes becomes startlingly apparent when the comparison is made digitally. The way I have presented the experimentation is also more scientific than might previously have been required, so that researchers who come after me can test my assumptions by following my method. I hope, too, that new software will be added to this, and new dynamics will be discovered.

Through an application of this experimental methodology I have shown that Cimabue developed skills of *disegno* that can be described as “photographic.” These skills were only fully rationalised and defined in the twentieth century by Betty Edwards and her son Brian Bomeisler. Cennini in the fourteenth century, Alberti in the fifteenth, and Leonardo in the sixteenth did not write about these “skills” in their treatises on painting in quite the same way, yet Cimabue seems to have used them long before they were supposedly thought of. It has been shown that this Florentine medieval artist made a quantum leap, far outperforming his contemporaries. However, much of his painting remains delicately Byzantine in its execution, with a linear formality associated with his time period, so that his tentative naturalistic approach can be described as remaining somewhat conventional. Nevertheless, although Cimabue’s sometimes exceptionally individualistic drawing skills *could have been* just genius, his ability to capture the millions of coordinates required to digitally re-manipulate the image nearly 800 years later is more difficult to dismiss. Traces of testable lens distortions in his painting make it difficult to refute his use of image projections. As I show in experiment thirteen, images from the San Domenico Arezzo *Crucifix* can be rotated on the third dimension without any loss of proportion or meaning. In fact, their aspect can be improved, as the way in which the portrait of Christ on the roundel becomes more natural, and St John’s stretched-out head is more pleasingly foreshortened.

Giotto, who appears not to have used image projections, takes from the painting of Cimabue and Duccio those lessons which he chooses. He doesn’t

illustrate “light” or “proportions” with such attention to individual variety. He shows little boys as scaled-down men, and still uses ratios that are formulaic and medieval. It appears that it was Cimabue and Duccio who first thought of making studies of children, and it seems almost certain that they used children as models where necessary, projecting images that enabled them to make accurate portraits. Advice on children’s proportions do not appear in the detailed practical painting treatises of Cennini or Leonardo, although Leonardo certainly depicted children. The preoccupation of Cimabue and Duccio to represent children as children was likely coincidental. As Christian artists they would have always been mindful of the sacred aspect of their work, and would have been more concerned with Christ’s divinity than his humanity. Certainly, towards the turn of the thirteenth century the idea of the humanity of religious figures was something new. It has been tempting for art historians to see humanism as a stimulus, yet I have shown that this is oversimplifying the situation, and even putting things the wrong way round. Although the concept of humanism might have been able to explain the why of naturalism, it failed to explain the how. Furthermore, the progression towards enhanced naturalism in Italian painting was not a neat path, as many artists who came after Cimabue and Duccio reverted to certain Byzantine proportions, and moved away from depictions of individualism back towards universalism, like the Lorenzetti in Siena and Giotto in Florence.

I have shown how the three significant Madonna altarpieces, now hanging together in the Uffizi Gallery in Florence, demonstrate the complexity of this relationship of influences between medieval Italian artists and among

medieval Italian artworks. I have demonstrated more believably why the Rucellai *Madonna* was able to hold the imagination of generations of Florentines. It has that aspect of the modern so admired by Vasari in the work of Cimabue. However, I have shown that its modernity must be reconsidered as an attention to the lessons of photographic detail. The Santa Trinità *Madonna* may have rightly replaced the Rucellai *Madonna* in terms of acknowledging its primacy, but only optical theory gives a proper understanding of the relationship between Cimabue and Duccio, and explains how Duccio learned the (optical) lessons of Cimabue, but developed his own very distinct style without difficulty. Image projections can be used by artists in any way which suits individual personality and skill.

It has also been shown more clearly that it was a sculpturality that Giotto brought to his work, rather than a naturalness, which made it Giottesque. Giotto lacks in the rather distinct individuality of style seen in Duccio's painting, and he remains more universally inclined. In this respect he is more the Italo-Byzantine heir than Duccio, who in many parts of his later *Maestà* makes a clean break with formula and universalism, particularly in the narrative scenes on the back panels. Duccio heralds the individualised narrative in Italian painting. However, for centuries the sheer size and scale of Giotto's work, coupled with his Florentine associations, foregrounded his *oeuvre* in the Italian imagination. Before the advent of twentieth-century photographic and reproduction printing techniques Duccio could not compete in this imagination. It is only recently, as I have already stated, that Duccio's work has been published in "full scale," where 1:1, and even enlarged, colour reproductions of

his paintings appear in books next to (reduced) reproductions of Giotto's frescoes.

Close computer analysis also helps to better understand the evidence of perspective in Duccio, both in examples of observable one-point perspective and in enigmatic anomalies like the rotating perspective in the scenes from the death of the Virgin on the predella (exps 33–37). Further, computer imaging also presents an accurate method of showing how, in the *Maestà*, Duccio maintained a remarkably accurate scale, and although some of his figures may have been traced from existing figures there is also enough evidence to suggest that many of the compositions are freshly posed (plates 28(xvi–xviii)). These fresh compositions represented on the back panels are all shown to be similar in magnification ($M = 0.16$) to that proposed for Cimabue's first image projection of the Christ figure for the San Domenico Arezzo *Crucifix* ($M = 0.17$), strongly suggesting that Cimabue and Duccio used the same systems as a similar magnification is also discovered for Duccio's medallion portraits ($M = 0.14$). I hope that these computer-based research methods will be enhanced by future researches resulting in an even more detailed clarification. Although I have not discovered the exact optical systems of the time, I have nevertheless shown that Cimabue and Duccio could have been using lenses or mirrors, or even both. Once the image was cast onto the receiving support this suggested “not only the outlines but everything in the middle” (to those artists who were privy to this information) as proposed by Cigoli (quoted in Camerota 2005:264) in the seventeenth century.

I have shown how an intimate knowledge of projected images seems to have greatly assisted in stimulating a new direction in Italian painting from 1270 onwards. This calls for a broadening of research into the crucial work of both Cimabue and Duccio, who have, for too long, been somewhat marginalised over the more populist figure of Giotto. Situating the use of projected images at the very start of the development of naturalism in medieval Italian painting does indeed, as Fendrich (2002:3) has stated, transfer “the ‘photographic’ flat image from a minor, late-game player in Western art to a member of the starting lineup.”

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NOTES

PREFACE

1. Artemisia Gentileschi, *Susanna and the Elders* (1610). Oil on canvas, 170 × 119 cm. Signed (on wall behind figure): ARTIMITIA / GENTILESCHI F / 1610. Collection of Graf von Schönborn, Pommersfelden, Bayern. Inventory: 191. (Christiansen & Mann 2001:296–9.)

INTRODUCTION

1. For example, see: Hyatt Mayor, A. 1946. The photographic eye. *Metropolitan Museum of Art Bulletin (New Series)* 5(1):15–26; Seymour, C. 1964. Dark chamber and light-filled room: Vermeer and the camera obscura. *The Art Bulletin* 46(3):323–331; Fink, DA. 1971. Vermeer's use of the camera obscura: a comparative study. *The Art Bulletin* 53(4):493–505; Mills, AA. 1998. Vermeer and the camera obscura: some practical considerations. *Leonardo* 31(3):213–218.
2. Although the Shroud is considered by some to be the actual image of Christ, others think of it as a painted object. See also, Allen, NL. 1995. How Leonardo did not fake the Shroud of Turin. *De Arte* 52:32–39.
3. David Stork, then a Consulting Professor of Electrical Engineering at Stanford, mounted a personal campaign to discredit this particular claim of Hockney's. He presented a paper in 2002 titled "Optical rebuttals to Hockney's explanations of 'opticality' in early Renaissance painting" (Stork 2002). He continued his assault on the Hockney thesis, alerting the press in August 2004 to the release of a paper he had written together with Cambridge computer expert Dr Antonio Criminisi (Criminisi & Stork 2004). Articles appeared in the *New York Times* and the *Sunday Herald* (Boztas 2004). Stork then published a further rebuttal paper, "Optics and realism in Renaissance art," which appeared in *Scientific American* December 2004.
4. The usual birthdate for Giotto is given around 1267. However, Ferdinand Bologna (1983:339) points out the following: "Some time ago Ragghianti drew attention to an unpublished document that had been brought to his notice by such authorities on the Florentine archives as Poggi and Procacci, in which a son of Giotto's name Francesco is mentioned as a 'priest' in 1301 (which means he must have been born not later than 1280), while Giotto's father Bondone appears to have been comfortably off in 1220. If these dates are confirmed, that of Giotto's birth must be put back at least ten years to 1267 [that is, to 1257], the date usually accepted."
5. This means that an artist, using a model who was clean shaven in the fashion of the day, would have had to make up a beard, or encourage the model to grow one for the duration of his employment with the artist.
6. As Robert Grosseteste had no access to Al-Haytham it can be assumed that Bacon cannot have become familiar with the Arab's optical treatises until at least after Grosseteste's death in 1253 (Lindberg 1974:392), therefore after he first came into contact with the stimulation of Chinese technology, rather than Arabic theory, certainly in my opinion.

CHAPTER 1

1. There is also a mention of a printed Parisian edition as early as 1542 (Davis 1992:51). Dee was an avid collector of ancient books and manuscripts, and in total his library consisted eventually of 4 000 volumes, 3 600 more than Cambridge University (Goldstone & Goldstone 2005: 180). He owned works of Aristotle, Avicenna, Albertus Magnus, Thomas Aquinas, Robert Grosseteste, Euclid, Ptolemy and St Augustine, amongst others (Goldstone & Goldstone 2005:180). He eventually also had in his collection thirty-seven of the hundred and seven Bacon works then known to be in existence, many of them originals (Goldstone & Goldstone 2005:180).

2. This is also quoted in Hockney (2001:206, under Textual Evidence:201–225). However, Hockney does not convincingly connect this medieval passage to his 1420 theory.
3. Such devices remind the author of a legend which records Caesar spying “into Gaul from the sea shore,” suggesting to him that the Roman general might somehow have had one of these instruments. Although this might sound unconvincing, nevertheless *see*, for example, Robert Temple *The Crystal Sun: rediscovering a lost technology of the ancient world* (2000).
4. In mentioning Al-Haytham, Smith seems to be also unaware that al-Haytham used the camera obscura to view images of the moon (Falco 2008).
5. Kenneth Rexroth reviewed Joseph Needham’s *Science and Civilization in China* when it first started to be published (1956), detailing his own excitement of the mammoth scope and importance of Needham’s work. “Some of Needham’s information is intrinsically exciting – for instance, the story of mammoth Chinese ships cruising the east coast of Africa and turning the Cape of Good Hope and venturing into the Atlantic before ever Vasco da Gama came the other way” (Rexroth 1956). It was over forty years before someone took up this challenge to received occidental maritime history, and even then the challenger was not a historian, but a retired submarine pilot with an interest in old maps (see Menzies 2003).
6. A website funded by a group calling themselves the “British born Chinese,” which makes the remarkable claim that by the time of the Mongol rule experimentation had been carried out in China for a variety of novel and unimaginably advanced concepts, including flying machines, the submarine, telescopes and the torpedo, all later considered too crude and rejected by the Ming Chinese in the fourteenth century (www.britishbornchinese.org.uk/pages/culture/history/mongols.html). This claim has been difficult to verify, but interestingly all the novelties cited, except the torpedo, are also mentioned in *De Mirabile*.
7. Shallow-keeled galleys were long in use on the Mediterranean, and although they did have sails they relied mostly on the power of ranks of oarsmen (Woodman 1997:20–21).
8. “Long before European craft sported more than one mast, the junk bore several. ... Adoption of bulkheads and the fore and aft rig mark the junk, already old practice when Marco Polo returned to Venice in the last decade of the thirteenth century, as a highly technologically advanced sailing ship, incomparably finer than anything produced in Europe. That the junk bore a high stern and a bow platform, giving it a rather clumsy appearance to western eyes, belies the effectiveness of hull and rig to fulfil its function. But there was yet another quality which, when it finally appeared in European ship-design, was to have a revolutionary effect. And this additional feature was the stern-hung rudder. ... Whether the concept of the rudder was the result of returning [European] traveller’s tales to advantage, the separate realisation of the idea in the west, or a simultaneous invention, will never be known” (Woodman 1997:39).
9. By the Yüan dynasty the Chinese had sails that reefed in a concertina fashion like a Venetian blind, making them more stable when riding anchor. See Gavin Menzies (2003) for information on how recent finds in China have started to corroborate early stories about the size and sophistication of medieval and early Renaissance Chinese junks. Joseph Needham, followed by Gavin Menzies and others, believed that Chinese junks had sailed round the tip of Africa and on into the Atlantic long before Vasco da Gama came the other way (www.bopsecrets.org/rexroth/essays/needham.htm). But how long before da Gama? This question is still to be satisfactorily answered.
10. It also seems very odd that Bacon, himself then also a teacher of Aristotelian philosophy, should send a formula for gunpowder to a bishop.
11. Even if one considers, like Davis, that the amount quoted is actually in Parisian pounds, which was worth about one third of English pounds, the amount is still an exorbitant £3.5 million sterling in today’s currency.
12. Yet, if we accept his authorship of *De Mirabile*, then we must also accept that, by 1250, he had also somehow seen fast-moving “great ships and sea-going vessels,” undoubtedly Chinese junks that could only have been witnessed by a traveller to the Far East.
13. Seneca could also have been referring to a journey *east* of Spain, not *west*. If an ancient Suez canal did exist, as reported by modern Israeli geologists in *Time Magazine* in 1975, then maritime traffic would have had direct access to the Red Sea from the

Mediterranean. “While studying aerial photographs of the Nile Delta after their country's 1967 conquest of the Sinai, Israeli geologists noticed soil markings that were clearly vestiges of two dried-up waterways. One was quickly identified as a silted offshoot of the Nile River called the Pelusiatic branch (after the ancient city of Pelusium at its mouth). The nature of the other waterway baffled the geologists until they visited the area and found man-made embankments. With that, they realized that these old mounds marked the route of a remarkable ancient canal that predated the Suez Canal by as many as 4,000 years” (*Time Magazine* Monday 20 October, 1975).

14. What Bacon was unsure of however, was just how “joined up” the “near” India of more common knowledge was with what he called “Farther India” (in other words, how big is the sea we now call the Pacific Ocean).
15. Bacon would have taken more than a few days just to cross the English Channel in a 20m long boat.
16. This is an area of early maritime history that needs to be more thoroughly researched, as my reinterpretation of Bacon's *Opus Majus* shows a medieval knowledge of world geography that is remarkable. Menzies (2003) supposition for the 1420 “discovery” of the “world” by China is probably too late, as the Chinese could have been sailing the deep waters of the Atlantic and the Pacific at least two centuries before this.
17. There is no indisputable mid point in longitude, such as the equator exists for latitude.
18. The sextant includes a telescope and a number of mirrors in its design (*Encyclopaedia Britannica* 2005. Sv “sextant”).
19. The idea to use astronomical events to calculate longitude was mentioned by Ptolemy (c.85–c.165) in the early Christian era. He advocated the method of Hipparchos (c.190–c.120 BCE), which was to “mark the precise moment when a heavenly event occurs [for example, a lunar eclipse], one which may be seen simultaneously across the globe” (Menzies 2003:368). However, it is thought that this method only became generally known in Europe around 1415, when Ptolemy's *Geographia* was taken to Venice by two Byzantines escaping the Ottomans (Menzies 2003:368). Further, Ptolemy's method required a diligent and precise way of measuring of time, that is, in a period when Western Europe had no clocks like the Chinese gnomons.
20. David Hockney, in his proposal for the use of optics as early as 1420, cites the writings of the Chinese master Shen Kua (Hockney 2001:205–206). Although he presents a passage from Shen Kua in his appendices, he fails to demonstrate how such information came into the hands of the artists he considers to be the first users of optics. Consider also that there is a long time gap, and a large geographical distance, between the Chinese Shen Kua of the eleventh century and the Flemish Jan van Eyck of the early fifteenth century.
21. To observe the phenomenon of an image projection, it is not necessary to darken the room completely. Hold up a simple magnifying glass in such a way that the scene outside the window (on a bright day) can be projected onto a wall or a piece of paper inside the room. The image will be quite clear, and is particularly startling if something outside the window is moving. The image will, of course, be upside down and reversed.
22. Bacon's mention of objects that are “in the house or in the street” is reminiscent of the later sixteenth-century descriptions of the camera obscura by Girolamo Cardano and Giovanni Della Porta.
23. Lindberg (1974:400) quotes an example of Witelo's blatant plagiarism, and failure to acknowledge his sources. “Ibn al-Haytham: ‘And we would say in the first place that sight occurs only by means of the glacial humor, whether sight takes place through forms coming from the visible object to the eye or in some other way. ... for if injury should befall the glacial humor, the other tunics remaining sound, sight is destroyed; if the other tunics should be corrupted, their transparency and the health of the glacial humor being retained, sight is not destroyed.’ Roger Bacon [acknowledges al-Haytham]: ‘The anterior glacial humor has many properties. The first and principal of these is that the visual power resides only in it, according to Alhazen and others. For if the glacial humor should be injured, the others being preserved, sight is destroyed; and if the glacial humor is preserved, injury befalling the others (provided their transparency remains), sight is not destroyed ...’ and Witelo [without acknowledgement]: ‘And so it is evident from these things that the glacial humor is properly the organ of the visual power, for the transparency of only this humor is receptive of the forms of visible objects, ... And if any

tunic or humor whatever, saving the glacial humor, should be injured, the eye ... is healed and sight is restored. However, when the glacial humor itself has been damaged, all of the sight is destroyed ...” (Lindberg 1974:400). Witelo, unlike Bacon, quotes no source, giving the impression that the knowledge is his.

24. The presence of a crucifix in the Dominican church in Bologna offers some difficulties to this claim for a Cimabue “first.” The crucifix (plate 29) in question is dated to 1250, and is now generally attributed to Giunta Pisano. On first impression the style and execution appears extremely similar to that of Cimabue’s *Crucifix* (plate 1) in Arezzo. With detailed analysis (exp 38) it even turns out to be a replica, with some interesting modifications. I reject, therefore, the dating of this crucifix and call for a re-attribution of the central figure of Christ to Cimabue. Turn to page 103 for further discussion.

CHAPTER 2

1. “Erano per l’infinito diluvio mali che avevano caciato al disotto et affogata la misera Italia non solamente rovinate quelle che chiamar si potevano fabriche, ma – quel che importava assai più – spentone affatto tutto il numero degli artefici, quando, come Dio voles, nacque nella città di Fiorenza l’anno MCCXL, per dare i primi luci all’arte della pittura, Giovanni cognominato Cimabue, della famiglia de’ Cimabuoi in quel tempo nobile” (quoted in Maginnis 1994:161–162).
2. The first Italian paper mill in Italy was begun in the 1270s, in Fabiano (Hallam 1853:458), and any “sheets” that Cimabue might have been able to use would have had to have been made from sheep’s parchment, at incredible expense. Vasari is most obviously expressing a Renaissance sentiment that to become a great master of painting required years of arduous training, and hours and hours of practice drawing (on paper).
3. “Avvenne che in que’ giorni erano venuti di Grecia certi pittori in Fiorenze, chiamati da chi governava quella città non per altro che per introdurvi l’arte della pittura, la quale in Toscana era stata smarrita molto tempo. Laonde, avendo questi maestri prese molte opere per quella città, cominciarono in fra l’altre la capella de’Gondi allato a la principale in Santa Maria Novella, della quail oggi dal tempo la volta e le facciare sono molto spente e consummate. Per il che Cimabue, comunicato a dar principio a questa arte che gli piaceva, si fuggiva spesso da la scuola e tutto il giorno stava a vedere lavorare que’ maestri” (quoted in Maginnis 1994:162).
4. “E dicesi che mentre Cimabue ditta tavola dipigneva in certi orti vicina l’orta S. Piero, non per altro che per avervi buon lume e buon aere e per fuggire la frequenza degli uomini, ...” (quoted in Maginnis 1994:162).
5. “[L]a quale, perciò ch’ ancora era state veduta da alcuno, mostrandosi al re, subito vi concorsero tutti gli uomini e tutte le donne di Fiorenza con grandissima festa e con la maggior calca del mondo” (quoted in Maginnis 1994:162).
6. Venice, for example, plundered four huge bronze horses for its Piazza San Marco, and a jewelled plaque that became the Pala D’Oro altarpiece of the cathedral (Eimerl 1967:38).
7. The idea of using transparency overlays of digitised images is also found in Falco & Hockney 2000 and 2003.
8. Hockney, and others, make it significant that Caravaggio left no drawings (see Hockney:123). However, I have discovered that Rubens most definitely made use of image projections, and he was a competent draughtsman. The fact that artists may have drawn, either freehand or using an image projection, or that they may have made preliminary drawings, is not, therefore, mutually exclusive to their use of image projections.
9. A copy of one of Cennini’s manuscripts is dated 1437, which is therefore thought to be the date of writing (Wikipedia. Sv. “Cennino Cennini.”). This is highly unlikely, and it is more probable that the manuscript was penned towards the end of the 1300s. Cennini claimed to have been born in Colle Val d’Elsa, and have been a pupil of Agnolo di Taddeo of Florence, who was a pupil of his father Taddeo, who had been a pupil and follower of Giotto (Cennini 1933:2). Using this genealogy Cennini’s birth can be placed sometime around 1350.

10. Betty Edwards recounts the following anecdote, to emphasize her point about upside-down drawing: “In 1838, the American inventor Elias Howe turned his attention to devising a sewing machine. After perfecting various features, he remained with one major problem: the needle. Needles had always had a point at one end and an eye at the other to hold the thread. Howe’s problem: how could such a needle pass all the way through a piece of cloth and come back up again in a continuous action when it had to be fastened at its eye end to the mechanism itself? The machine couldn’t ‘let go’ of the needle to pull it through to the other side of the fabric, as happens when a person is sewing with a needle. Howe could not ‘see’ a needle in any other way until one night he dreamed of being attacked by savages carrying spears that had eye-shaped holes near their tips. Ah-Ha! Howe awakened from his dream and immediately whittled a sewing machine needle with the hole at the pointed end. The problem was solved, essentially by it being turned upside-down” (Edwards 1988:27).
11. This particular lens distortion of inadvertent elongations is introduced by Hockney in *Secret Knowledge* (2001:179).
12. I unconsciously did this myself when I built a camera obscura and traced from an image projection (see exps 1 and 2, and the correction exp 30).
13. During the heavy flooding of Florence in 1996, this crucifix was submerged in raging torrents of muddy water, and large parts of it were irretrievably damaged. It was restored in 1996 to its current condition.
14. The relationship between the proportions of the figures and the ground on which they appear, that is, in the case of a wooden crucifix the prepared wooden surface itself, is not always cohesive. As Bernadette van Haute pointed out to me in reference to the San Domenico Arezzo *Crucifix*: “I suggest that the panel was precut according to standard size but when the figure was projected, the arms came out longer than in previous artworks. This caused the artist to push Christ’s fingers into the adjoining panels of St Mary and St John. He seems to have made provision for the longer arms in the later Santa Croce *Crucifix*” (feedback on thesis draft 12 May, 2008).

CHAPTER 3

1. “Long before the present church was built there stood on this spot a small chapel called St. Mary in the Vineyard. This having been destroyed, the Dominicans, with the assistance of the Rucellai family, began the new St. Mary’s in the year 1279. The design for the church was prepared by three Dominican friars, and is Italian Gothic, the shape being a Latin cross. The long nave is raised midway by one step, so that one seems to rise by slow degrees from the west door to the High Altar and to the group of chapels on either side of the choir.” (http://numberonestars.com/travel/florence_santa_maria_novella.htm)
2. The Rucellai *Madonna* is firmly dated to 1285, and many scholars favour a dating of around 1270 for the San Domenico Arezzo *Crucifix* (Bellosi 2001:17). Although I consider the San Domenico Arezzo *Crucifix* to have been done after Cimabue sojourned in Rome (1272), it was certainly executed after 1268 when the first knowledge of image projections reached Italy.
3. I am not suggesting that Cimabue knew of the Chinese sources of optics. However, it must be noted that European contact with Mongolian ruled Yuan Dynasty China was much more prevalent than is generally understood. In 1264 Kublai Khan, grandson of Genghis, transferred his capital from Karakorum in Mongolia, to Beijing in north China (also Daidu – “great capital” and Peking). He adopted a dynastic Chinese title, Yüan (“great beginning”) in 1271, and made his focus a united China that included Mongolia, Manchuria and Tibet. (Buckley Ebrey 1996:172–73.) Trade and relations with Europe increased substantially, particularly with the Italian peninsula. “[I]n the middle of the thirteenth century it was Italy ... where international commerce was revived, which lay at the geographical centre of a network of trade routes radiating out from the Mediterranean, and also at the focal point of a system of currency and credit, and of business organization” (Phillips 1998:96–7). This period saw an intensification of

east/west contact that had been reinitiated many decades previously. “[T]he extent of medieval European contacts with other continents was much greater and far more persistent than is generally realized” (Phillips 1998:vii). In 1279, a year after Duccio received his first known commission in Siena, the Southern Song dynasty in China finally collapsed under the rising pressure of Mongolian expansion. The whole of China was now under Mongolian rule. Europeans, especially the Italians, were quick to see the opportunities in travelling to places closed to them for a millennium (Phillips 1998:76).

4. There were many Tartar slaves in Italy at this time, and in 1287, for example, a Nestorian bishop from North China, Bar Sauma, made an historic visit to Italy. He is sometimes called “Marco Polo in Reverse” (Boser 2004:60).
25. St Catherine was famous for being instrumental in bringing the papal seat back to Italy from Avignon in 1377 (*Encyclopaedia Britannica* 2005. Sv “Saint Catherine of Siena”).
5. The idea that early sculptors, even medieval ones, might have used optical projections has occurred to me on occasion. This warrants future research in an historical broadening of this thesis to include other art forms such as sculpture.
6. “Critics indeed are not unanimous even as regards the Castelfiorentino and Crevole Madonnas. White says nothing of the former work, but accepts without hesitation the general view that the second is a masterpiece by Duccio, some years earlier in date than the Rucellai Madonna. Stubblebine, on the other hand, denies the Crevole Madonna to Duccio and makes it the chief work of a Siennese painter in the style of Cimabue, who came under Duccio’s influence from about 1285; while he attributes the Castelfiorentino Madonna to the earliest and most Cimabuesque period, between 1280 and 1285, of the ‘Master of Badia Isola’” (Bologna 1983:337).
7. One must recall here that the “Giunta Pisano” that Zuffi is referring to, I have reattributed to Cimabue, that being the San Domenico Bologna *Crucifix*.
8. The complete text of Witelo Lib.VII.Prop.60 is published in David Hockney’s revised edition of *Secret Knowledge* (2006:242), and was supplied to me by David Graves (email 25 February 2006). “Take a convex cylindrical mirror, let its line of axis be abc . Let it be stood upright on its pedestal, somewhere in a suitably spacious house, so that the line ac , centre point b , is upright over the floor of the house. Let a line be drawn cutting the mirror at point b , perpendicular to line ab , which shall be dbe which, following the line of points, d and e should touch the walls of the house and these points should be marked on the walls. Therefore the surface on which line dbe lies, which is at right-angles to the axis of the mirror, clearly cuts through the mirror describing the curve. Therefore above point d make a point f on the wall so it can easily be made closer still. Let a line be extended from point f which is equidistant from the line of the mirror, of whatever length you like, let this be gfh , centre-point f , and let the line fb be joined-up and extended through the wall to point k . Let the wall be cut through along line gfh , and on the other side of the wall, opposite the mirror, let the hole be made larger, just as is usual with the windows of a house. The cutting of the opening should follow the line bfk , and let the opening be fk . From the point on the mirror which is b let a straight line be extended from the surface of the mirror, at an angle above line dbe which, extended beyond the mirror, shall be bm . Also, at point b , at the end of line bm and at the angle of kbm , let there be an equal angle which will be mbn when the line bn is drawn. Also, join the mirror to points g and h , which are the end-points of line gfh . Let them be ga and hc , which, extended, run together at point o . Let the line bo be drawn cutting the circular plane at b , and let there be a similar intersection for bn , so it may be equivalent to bo . I say that if the centre of vision is placed at point n , to which is reflected the image of line gfh from the axis of the mirror, which is abc , the whole of line gfh will be seen, quite clearly, outside the mirror, between the mirror and the line gfh , and definitely close to point d on line de , which touches the mirror at point b . If therefore, lines og and oh are extended through the wall to points p and q , and one line is joined, let that be pkq . Let a board, with a painting somewhere on it, be arranged on this line outside the wall, so that the middle of the picture painted on the board is placed on line pkq , and is positioned in such a way that the picture on the board cannot be seen from the existing line of vision at point n or near it. Nevertheless, with visibility so arranged, the image of the picture will be seen reflected in the air from the surface of the cylindrical mirror. I seriously believe that in a similar way it is possible to set up pyramidal convex mirrors and the

centre of vision. From spherical convex mirrors such a reliable image would not result as from the mirrors proposed. The proposition is complete. The eager enquirer following this method should be on his guard for in this current theorem which we have presented we have made use of this as an example so that by the circulation of Book Seven the way to seek knowledge of diverse skills may be open to the enquiring mind.”

9. Giotto was not known as a painter before the shaky attribution of the Santa Maria Novella *Crucifix* to him, dated around c.1300. His first really secure fresco commission was for the Scrovegni Chapel in Padua, dated c.1305. At this stage Giotto was nearly 40, but he could also have been nearly fifty if his birth date is pushed back to 1567 (Bologna 1983:339).
10. It is likely, in keeping with accepted practice, that Duccio also never used women as models, and that the model for this older Mary was a more mature man than the young boy he undoubtedly used for the young Mary.
11. Horizontal parallel lines appear to recede into space and converge on a horizontal vanishing point.
12. Leonardo da Vinci, *Annunciation* (1478–1480). Tempera on wood, 98 × 217 cm. Uffizi Gallery, Florence.
13. Duccio’s exact working procedures are difficult to determine because the altarpiece was dismantled in the eighteenth century. White (1979:93) considers that the carpentry was fully assembled before painting began, in other words, the artist faced what was, in effect, a large wall. “Nevertheless, the structural evidence makes it most improbable that the predella could have been attached to the main body after painting. It is even less likely that the pinnacle panels were slotted into position after completion. In most contemporary altarpieces the pinnacle panels are of one piece with the main body. Although its special construction meant that in the *Maestà* they were not, the physical integration of the front pinnacles as well as the evidence of the contract, preclude their attachment to the main body after painting began. Indeed, the actual work of painting a large panel was much more like frescoing a wall than might at first be thought.” If White is correct then to achieve the unusual (copied) anamorphosis as found in the *Arrival of St John the Evangelist* it would have meant that the artist was working with preliminary drawings, and then tracing these preliminary drawings onto the prepared (single) panel. It may have been that Duccio realised the distortion at some point, and liked the “widening/narrowing” effect which gave more room for the apostles to gather, but subtly suggested a suffocating of the Virgin in her increasingly narrow space.
14. Despite the many positive aspects of Tsuji’s suggestion, his hypothesis appears to have engendered no further comment and thereafter slipped very much into obscurity, so much so that even David Hockney, with all his enthusiasm for the camera, seemed unaware of it. Also unfortunate for Tsuji’s hypothesis is that Hockney’s more vociferous proposal for a camera obscura, but one with a mirror-lens, actually takes a step back from Tsuji’s research as it fails to take into account the need for a reversed image to satisfy Brunelleschi’s peepshow requirements. It is this peepshow demonstration that demands the panel to have been reversed, in other words that it was a mirror image. Manetti reports that Brunelleschi drilled a hole in the panel exactly “where the eye struck” (quoted in Tsuji 1990:277), the place we now call the vanishing point. The hole was a cone shape, so that it was smaller in the front (about the size of a lentil) and larger at the back. The viewer, positioned just inside the cathedral door from where Brunelleschi had done the painting, held the painted panel backward to the face and looked through the hole at a mirror reflection. Moving the mirror away it was said to be difficult for the viewer to distinguish between the reflection of the panel and the real scene, testament to the panel’s verisimilitude to the Baptistery.
15. Nevertheless as I have stated before, the ability to project full-size human figures could have been achieved, and such a possibility should not be dismissed out of hand.
16. On the other hand, it should be borne in mind that it is *more difficult* to accurately draw portraits freehand when the model is posed three-quarters.
17. In contrast, David Hockney (2001:36–41) finds cloth convincingly depicted, and pattern neatly following the folds, only from 1400 onwards (his 1420 theory). Duccio therefore is either an optical exception to Hockney’s theory, or an earlier user of optics, as I propose. This is therefore an area that requires further detailed research in the future.

18. The later artist, Caravaggio, actually placed an old carthorse right inside his studio (Robb 2000:162).
19. David Hockney cites his suspicions of Giorgione as a user of optical aids (2001:42–43). I added Titian to the list in my Master's Dissertation (Grundy 2004). See also Grundy 2004a.
20. Titian, *Portrait of Daniele Barbaro* (1545). Oil on canvas, 81 × 69 cm. Museo del Prado, Madrid (*Web Gallery of Art* 1996.)
21. “San Giorgio si muove in un impeto irruente, nell’atto di trafiggere il drago, mentre il cavallo si torce a causa del movimento del cavaliere e del contatto con il drago” (Baragli 2005:275).

APPENDIX

Experiments

EXPERIMENT 1

16 September, 2004

Aim

To create an ordinary concave-mirror projection, and to paint the results onto a small cotton board using Acrylic paints.

Equipment

1. Black bin bags and masking tape.
2. Two small medium grain 100% cotton boards: 12×17 cm and 15×20 cm.
3. Paint brushes and four tubes of Acrylic paints (red, blue, yellow and white).
4. Selection of fruits and fruit basket.
5. Two high stools.
6. Domestic concave shaving mirror, focal length 35 cm.

Method

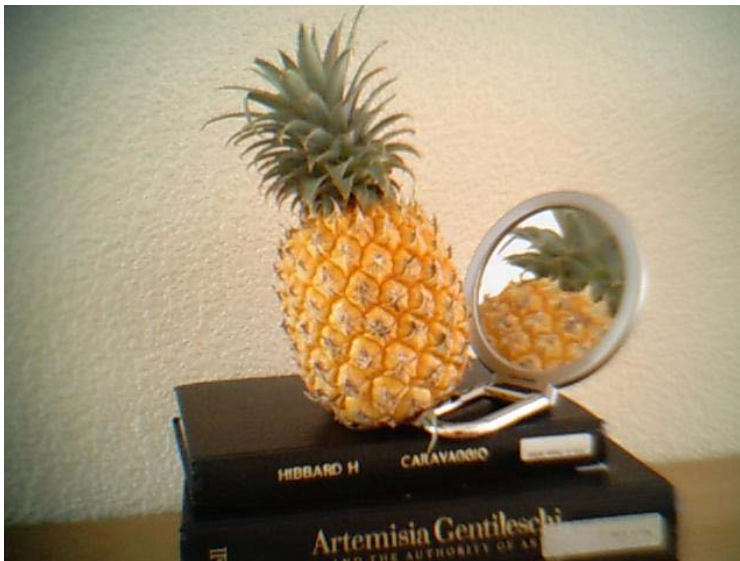
1. I first set up the “camera obscura” by taping black bin bags to the windows of a small study, leaving a “window” of about 30 cm^2 .
2. I worked early in the afternoon, when the sun was fairly high, around 2 o'clock.
3. In a small courtyard, on the other side of the window, I placed a high stool at the same height as the “window,” and arranged a small basket of fruit.
4. I placed the concave mirror onto another high stool inside the “camera obscura,” in line with the window, and at a distance of about 1 m.
5. The object was placed outside in bright sunlight, about 2.5 m from the lens (that is, about 1.5 m from the window).
6. I taped a small canvas board, 12×17 cm, to the wall alongside the small window.
7. Angling the concave mirror, I captured the image projection onto the canvas, and painted the small work *Concave Fruits I*.
8. The small painting took me about half-an-hour, and is a magnification of 0.17.
9. I then moved the basket of fruit closer to the lens, (1.87 m), and produced the slightly larger work *Concave Fruits II*, at a magnification of 0.24.
10. Finally, I placed the pineapple separately onto the high stool support, and photographed the resulting concave-mirror projection using a digital cell-phone.

Observations

1. The equipment I used was basic, and setting up a small canvas to receive a concave-mirror projection was a relatively simple process
2. I worked quickly, and found that the projection greatly facilitated the speed with which I could work
3. The images were, however, very small, so that certain details were difficult to visualize, like the very specific patterns of the outside of the pineapple and the detail of the leaves. However, with the basket of fruit slightly closer to the lens, and the image therefore somewhat enlarged, it was easier to see the details.

Conclusions

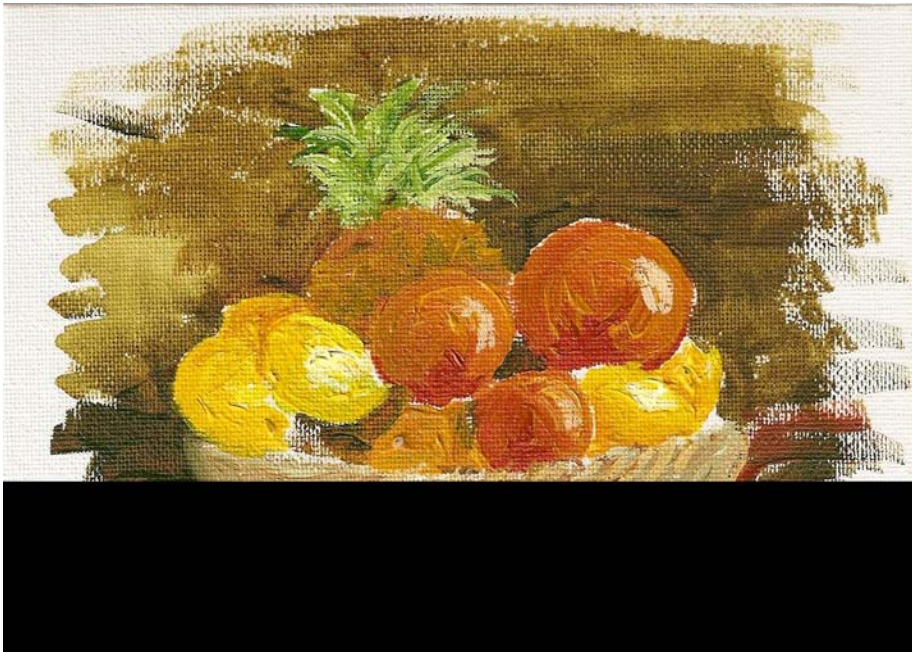
From this experiment I conclude that it is extremely simple to set up a camera obscura using a concave mirror to project a real image of an object set up outside in direct sunlight. Some detail is lost, but the availability of basic shapes and colours makes the production of a realistically-styled artwork a relatively simple affair. It is not that difficult to paint in the relative dark using an image projection. I did not find that the fact that the image was upside down was of any hindrance to my observational powers.



Experiment 1. Figure a) A digital photograph showing the concave mirror in relation to a pineapple.



Experiment 1. Figure b) A digital photograph showing a concave-mirror projection of a pineapple.



Experiment 1. Figure c) Susan Grundy, *Concave Fruits I* (2004). Acrylic on cotton board, 12 x 17 cm. (Scanned 23 November, 2007.)



Experiment 1. Figure d) Susan Grundy, *Concave Fruits II* (2004). Acrylic on cotton board, 15 x 20 cm. (Scanned 23 November, 2007.)

EXPERIMENT 2

24 September, 2004

Aim

To create an image projection using a simple magnifying glass, that is, a convex lens, and to paint the results onto a cotton board using Acrylic paints.

Equipment

1. Black bin bags and masking tape.
2. Thin black board.
3. Artist's easel.
4. A medium grain 100% cotton board measuring : 305 x 254 cm.
5. Paint brushes and four tubes of Acrylic paints (red, blue, yellow and white).
6. A pineapple.
7. A high stool.
8. A convex lens (magnifying glass), focal length 25 cm.

Method

1. I first set up the "camera obscura" by taping black bin bags to the windows of a small study, leaving a "window" of about 30 cm².

2. I then made a small hole of about 5 mm in diameter in the thin black card, and taped this to the remaining “window,” so that the only light entering the room was through this small hole.
3. I then taped the magnifying glass (convex lens) in front of the hole, so that the light shone through the hole *and* the lens.
4. I worked early in the afternoon, when the sun was fairly high, around 2 o’clock.
5. In the small courtyard, on the other side of the window, I placed a high stool at the same height as the “window,” onto which I arranged a pineapple.
6. The object was placed outside in bright sunlight, about 50 cm from the lens.
7. I placed the canvas board onto the artist’s easel at a distance of about 50 cm from the lens, inside the “camera obscura.”
8. I focussed the image projection onto the canvas by moving the easel slightly back and forwards until I was satisfied, and then painted the work *Lens Pineapple*.
9. The painting took me about half-an-hour, and is a magnification of 1.

Observations

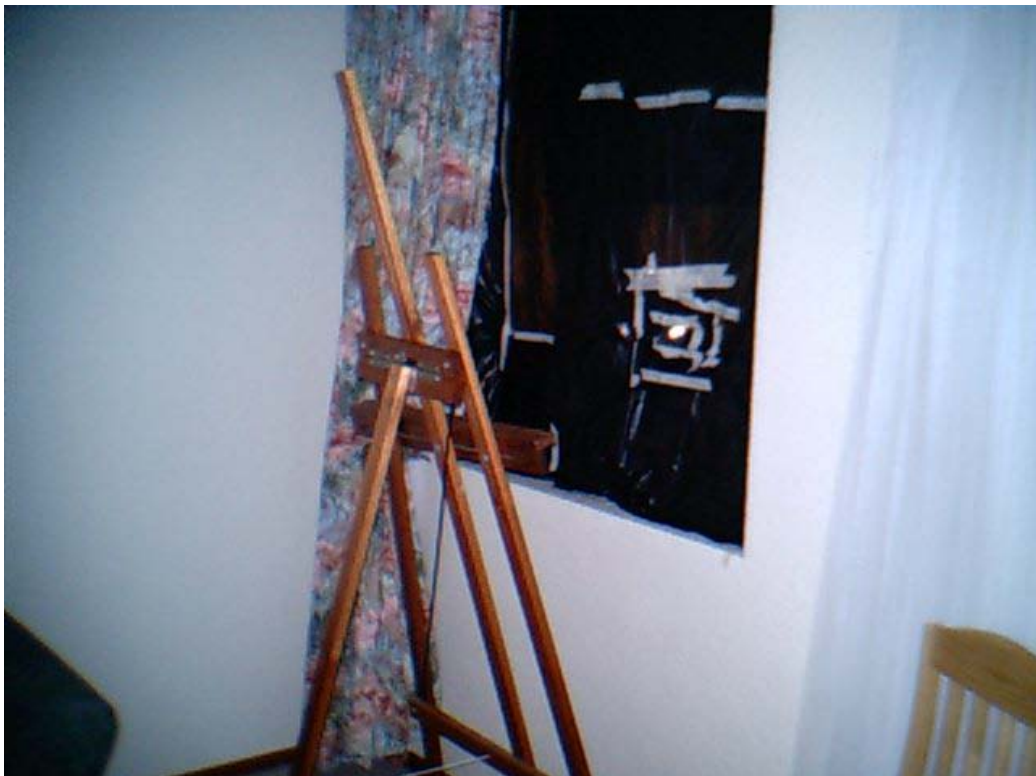
1. Again, the equipment I used was basic, and setting up the canvas to receive the image projection was a relatively simple process.
2. I worked quickly, and found the projection greatly facilitated the speed with which I could work.
3. At a magnification of 1 I was able to see, and therefore to capture, much more detail than I could for the small image projections created by the concave mirror.

Conclusions

From this experiment I conclude that it is extremely simple to set up a camera obscura using a convex lens to project a real image of an object set up outside in direct sunlight. It is also not difficult to create a real image at magnification of 1, where the object being projected is not bigger than 30 cm (that is, a pineapple or a human face). It is not at all difficult to paint in the extreme dark using a convex lens image projection. I did not find that the fact that the image was upside down was of any hindrance to my observational powers.



Experiment 2. Figure a) A digital photograph showing the lens in relation to a bunch of poppies.



Experiment 2. Figure b) A digital photograph showing the artist's easel and the taped blackened window, with the small hole and lens taped in front of the hole.



Experiment 2. Figure c) Susan Grundy, *Lens Pineapple* (2004). Acrylic on cotton board, 305 x 254 cm. (Scanned 19 November, 2007.)

EXPERIMENT 3

16–17 September, 2007

Aim

To test the proportioning of the San Domenico Arezzo *Crucifix*, Pisa *Crucifix No 15* and Pisa *Crucifix No 20*, against the *Universal Male* from *Liber Divinorum Operum*, Leonardo Da Vinci's drawing of *Vitruvian Man*, and a modern anatomical drawing as control.

Equipment

CorelDRAW X3

Method

1. I placed the *Universal Male*, the figure of Christ from Pisa *Crucifix No 15*, and the figure of Christ from Pisa *Crucifix No 20* together, and tested their proportions against a box drawn with the **Rectangle Tool** to 5 cm².
2. I then placed the Christ figure from the San Domenico Arezzo *Crucifix* into a box of 5 cm².
3. I placed Leonardo's *Vitruvian Man* and the modern anatomical drawing into a box of 5 cm².
4. I placed the modern anatomical drawing inside of a box of 5 cm².

Observations

1. The head of the *Universal Male* is relatively large, being 1/7 of the body and not 1/8 as described by Vitruvius.
2. The *Universal Male* fits into a square, with outstretched arms equal to height (making compensation for the fact that the arms are not shown fully outstretched).
3. The arms of the Christ figure from Pisa *Crucifix No 15* are relatively short, and this figure does not form a square, that is, according to the rule of Vitruvius that the length of a man's outspread arms is equal to his height.
4. The Pisa *Crucifix No 20* forms a square, that is, according to the rule of Vitruvius that the length of a man's outspread arms is equal to his height.
5. The Christ figure from the San Domenico Arezzo *Crucifix* inscribes a square, with outstretched arms equal to height (making compensation for the slight sway of the body to the one side).
6. Leonardo's *Vitruvian Man* inscribes a perfect square, with outstretched arms equal to height.
7. The modern anatomical drawing inscribes a perfect square, with outstretched arms equal to height.

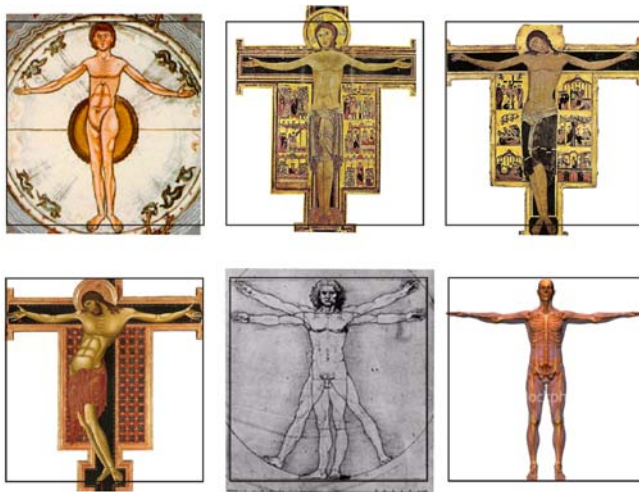
Conclusions

From this experiment I conclude that the proportioning of the Christ figure in the San Domenico Arezzo *Crucifix* and in Pisa *Crucifix No 20*, are the most "Vitruvian" of the examples from the middle ages, and measure up well to the

proportioning of the figure from Leonardo da Vinci's *Vitruvian Man*, drawn two hundred years later. The Pisa *Crucifix No 15* is the least Vitruvian.



Anatomy of a male. (Available at: www.istockphoto.com)



Experiment 3. Figures placed inside a box to test "Vitruvian" proportions.

EXPERIMENT 4

17 September, 2007

Aim

To further test the proportioning and anatomical approach of the San Domenico Arezzo *Crucifix*, Pisa *Crucifix No 15* and Pisa *Crucifix No 20*, and *Vitruvian Man* against a modern anatomical drawing.

Equipment

CoreDRAW X3

Method

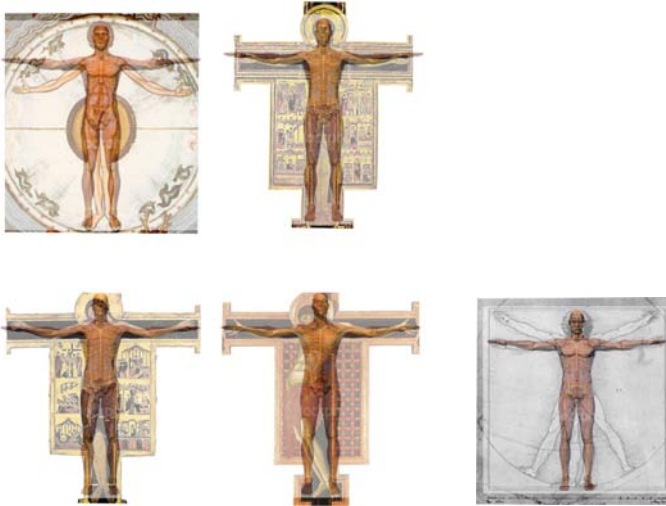
1. I made an extra copy of the modern anatomical drawing and used the **Interactive Transparency Tool** to make this copy of the drawing 50% transparent.
2. I placed this transparency over all the other figures, from the sample, in order to compare the anatomical proportions.

Observations

1. The head of the *Universal Male* is slightly large, in comparison to the modern anatomical drawing, but the rest of the figure is relatively in proportion, for example, the ribcage, pelvis, knees and ankles are well positioned. However, the lateral torso is somewhat narrower.
2. In Pisa *Crucifix No 15* the sternum is well placed, but the ribcage too narrow in comparison to the modern anatomical drawing. The lateral torso is narrower, but the pelvis, knees and ankles are well placed. The arms are shorter by almost a hand's length.
3. In Pisa *Crucifix No 20* the sternum is well placed, but the ribcage too narrow in comparison to the modern anatomical drawing. The lateral torso is narrower, but the hips are comparable. However, the figure has more elongated legs.
4. The Christ figure from the San Domenico Arezzo *Crucifix* fits comparatively well with the transparency of the modern anatomical drawing. The lateral torso is well defined, as is the height of the sternum and the shape of the ribcage. The arms are slightly elongated over the modern anatomical drawing, but the muscles are accurately placed. The pelvis, knees and ankles are all comparatively placed. However, the left shoulder is twisted and distorted, and looks almost as if it has been dislocated.
5. Leonardo's *Vitruvian Man* makes the best comparison with the modern anatomical drawing. It is an almost perfect fit.

Conclusions

From this experiment I conclude that the San Domenico Arezzo *Crucifix* is remarkably sophisticated in its anatomical accuracy in comparison to the other Pisa examples. However, the early Pisa crucifixes cannot be dismissed as totally unrealistic.



Experiment 4. Figures superimposed with a modern anatomical drawing at transparency 50%.

EXPERIMENT 5

20 September, 2007

Aim

To discover the centre of gravity in Pisa *Crucifix No 20* and to compare this to the centre of gravity in the San Domenico Arezzo *Crucifix*.

Equipment

CorelDRAW X3

Method

1. I placed Pisa *Crucifix No 20* onto a page alongside the San Domenico Arezzo *Crucifix*.
2. Using the **Freehand Tool** I drew a straight 4pt rule in red, line AB.
3. I placed the line AB over Pisa *Crucifix No 20*, using the figure's nose as the centre of gravity.
4. I then placed the line AB over the San Domenico Arezzo *Crucifix*, using the figure's nose as the centre of gravity.

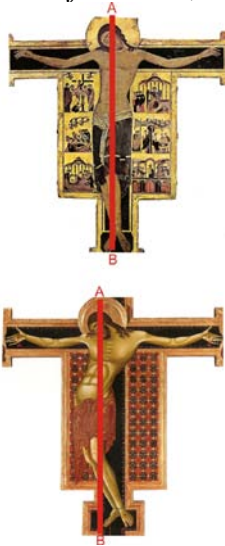
Observations

1. The line AB in Pisa *Crucifix No 20* runs through between the two feet, only marginally off centre.
2. The line AB in the San Domenico Arezzo *Crucifix* runs off centre to the right of the figure, approximately one hand's length away from where the centre of gravity should be.

Conclusions

I conclude from the positioning of the centre of gravity in the *San Domenico Crucifix* that the model was not supported by his own two feet. On the other

hand, the centre of gravity runs through the positioning of the feet in Pisa *Crucifix No 20*, suggesting that the model was indeed standing.



Experiment 5. Figures placed to show centre of gravity.

EXPERIMENT 6

22 September, 2007

Aim

To establish the outlines, or underlying contour drawing, in Pisa *Crucifix No 20* and to compare this with the underlying contour drawing in the San Domenico Arezzo *Crucifix* (pre-restoration 2001).

Equipment

CorelDRAW X3

Method

1. I placed two same-sized images of Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix* onto an empty page, and used the **Art Strokes, Sketch Pad Tool** to convert the bitmaps to outline sketches.
2. I used the Graphite Pencil set to HB.
3. The other parameters, Style and Outline, were set to medium.

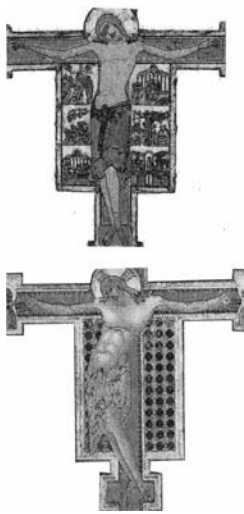
Observations

1. In Pisa *Crucifix No 20*, the outlines of the arms attach to the body in a jarring way, so that the arms look like thin sausages stuck onto the lateral torso.
2. In the San Domenico Arezzo *Crucifix* the outlines of the arms are more predominant at the top, and flow around the scapulae into the hair line. The outline lifts to suggest the pull of the skin underneath the arm, marking the armpit.
3. In Pisa *Crucifix No 20* there is no demarcation of the armpit, and the line joins the body in a simplistic way.

4. The hair in *Pisa Crucifix No 20* is outlined like a cap, whereas in the *San Domenico Arezzo Crucifix* the softness, and individuality of the hair is clearly suggested.
5. The shape of the legs in the *San Domenico Arezzo Crucifix* shows an individual outline, as opposed to the *Pisa Crucifix No 20* where the line is straight, finite and simplistic, echoing the same naive approach of the arms.

Conclusions

I noted that the computer tool **Art Strokes, Sketch Pad** suggested a far more sophisticated, underlying contour drawing in the *San Domenico Arezzo Crucifix*, when compared to *Pisa Crucifix No 20*.



Experiment 6. Figures shown as improvised “sketches.”

EXPERIMENT 7

22 September, 2007

Aim

To show the negative spaces in the *San Domenico Arezzo Crucifix* (pre-restoration 2001), and to compare and contrast this with the negative spaces in *Pisa Crucifix No 20*.

Equipment

CorelDRAW X3

Method

1. I placed the *San Domenico Arezzo Crucifix* and *Pisa Crucifix No 20* onto a computer page in exact same image sizes.
2. I transformed them into an appearance of photographic negatives by inverting the colours using the **Transformation Tool, Invert** procedure.

Observations

1. The negative spaces, both within and without the Christ figure of Pisa *Crucifix No 20*, emphasize the symbolic elements, for example, as in the way the arms have been described, which are bendy rather than articulate.
2. In comparison, the negative image of the San Domenico Arezzo *Crucifix* startles like a modern X-ray plate. The negative shapes, both within and outside the body, are well-defined and complex, as for example, the shape the swaying body makes against the background of the cross.

Conclusions

From this experiment I conclude that the Christ figure from the San Domenico Arezzo *Crucifix* is indeed, very “modern” in its appearance, and that the artist has understood the concept of negative space.



Experiment 7 Figures shown as photonegatives.

EXPERIMENT 8

23 September, 2007

Aim

To show the proportions in the San Domenico Arezzo *Crucifix*, and to compare these to the proportions in Pisa *Crucifix No 20*.

Equipment

CorelDRAW X3

Method

1. I scaled the “face” – that is from the hairline of the forehead to the tip of the chin – of Pisa *Crucifix No 20* to measure exactly 12 mm.
2. I then placed as many “faces” as needed to reach the feet, taking into account a rough estimate of where the head would be placed if the figure was to have been represented standing upright.

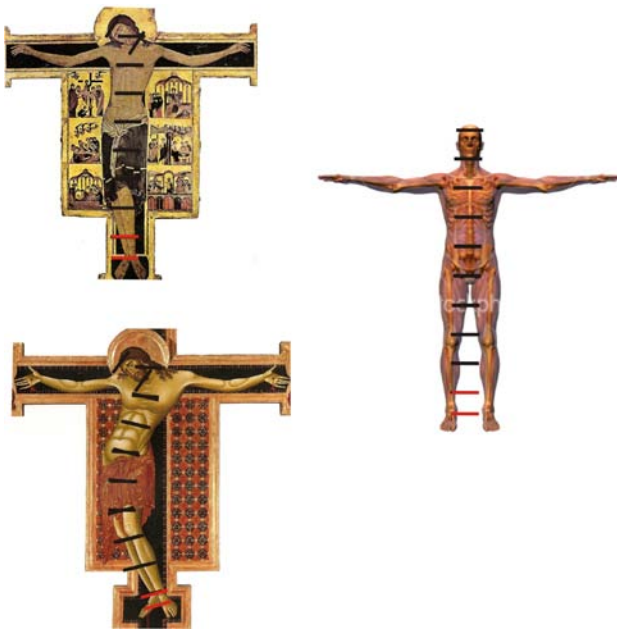
2. I used the same scale and measurements for San Domenico Arezzo *Crucifix*.
3. As a control measure, I applied the same scale and measurements to the modern anatomical diagram of a man. (As the figure is represented bald, I estimated the hairline.)

Observations

1. The whole body of Pisa *Crucifix No 20* measures $8\frac{2}{3}$ faces, as proposed by Cennini (that is, 104 mm to the set scale).
2. In comparison, the figure of the San Domenico Arezzo *Crucifix* is elongated, measuring $9\frac{1}{3}$ faces (that is, 112 mm to the set scale).
3. The anatomical diagram of a modern man is longer than advised by Cennini, that is at $9\frac{2}{3}$ faces as compared to $8\frac{2}{3}$ (116 cm to the set scale).

Conclusions

I concluded that even although Pisa *Crucifix No 20* measured up to the $8\frac{2}{3}$ faces recommended by Cennini, the “correct” proportions were those of the San Domenico Arezzo *Crucifix*, that is, $9\frac{1}{3}$ faces as seen in the anatomical diagram of a modern man.



Experiment 8. Graded markings showing proportions.

EXPERIMENT 9

23 September, 2007

Aim

To test “light logic” in the San Domenico Arezzo *Crucifix* (pre-restoration 2001), that is, the enhancement and manipulation of light and dark by the artist, and to compare this to the “light logic” in Pisa *Crucifix No 20*.

Equipment

CorelDRAW X3

Method

1. I converted images of Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix* to Greyscale (8bit) using the **Convert to Bitmap Tool**.
2. I then adjusted the contrast between light and dark to 100%, using the **Brightness/Contrast/Intensity Tool**.

Observations

1. The light and dark areas on the figure of Pisa *Crucifix No 20* remained relatively indistinct.
2. The strongest highlights on Pisa *Crucifix No 20* are on the face – bridge of the nose and eyelids – and a little on the neck.
3. There are very few shadow areas defined on Pisa *Crucifix No 20*.
4. On the other hand, the central figure of Christ on the San Domenico Arezzo *Crucifix* is marked by areas of strong highlights, especially predominant on the muscle groups like the pectorals, biceps, as well as on the face.
5. Further, medium shadows are well defined on the figure in the San Domenico Arezzo *Crucifix*.
6. There are some very dark areas as well on the San Domenico Arezzo *Crucifix*, such as in the armpits, and on the back leg.

Conclusions

The artist of the San Domenico Arezzo *Crucifix* shows a sophisticated comprehension of light and dark, and exhibits a strong sense of light logic. On the other hand, the artist of Pisa *Crucifix No 20* has only marked a very rudimentary suggestion of light and dark, and therefore cannot be said to have exhibited a sense of light logic.



Experiment 9. Figures manipulated to enhance "light logic."

EXPERIMENT 10

18 September, 2007

Aim

To consider the size of the probable projected image in relation to the Christ figure in Cimabue's San Domenico Arezzo *Crucifix*.

Equipment

CorelDRAW X3

Method

1. I measured the image of the Christ figure to fit into an area of 30 cm².
2. I then cropped this image to fit into an A4 page, for display purposes. I then applied a special effect using **Motion Blur** to simulate a slight lack of focus to the image (as it would be using a simple concave mirror or biconvex lens). This technique effectively blurs the pixels into each other.
3. I then rotated the image upside down, to further simulate how the projected image of this figure would have appeared to the artist.

Observations

The image affords enough information to strongly suggest an accurate rendering of both proportion and surface anatomy, in other words, how the muscles and bones appear on the surface of the body.

Conclusions

Even a small, slightly blurred image, offers enough information for an artist to achieve far greater detail that would be available to an artist painting by eye. This would particularly benefit the placing of proportions.



Experiment 10. Figure shown inverted as it would have been for an image projection.
 Note: The artist would have been studying the image of a live model. The painting is used for illustrative purposes only.

EXPERIMENT 11

2 November, 2007

Aim

To compare and contrast the underlying contour drawings, the use of negative spaces, and the inherent light logic in the San Domenico Arezzo *Christ Blessing* roundel to the portrait of Christ in Pisa *Crucifix No 15*.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then tested the underlying contour drawings, the use of negative spaces, and the inherent light logic by running the images through the same diagnostics as Experiments 4, 5 and 7.

Observations

The tests show that in all instances the San Domenico Arezzo *Christ Blessing* exhibits superior drawing skills. In testing the underlying contour skills, the artist of the San Domenico Arezzo *Christ Blessing* used a much more subtle line than the artist of Pisa *Crucifix No 15*, who applies solid outlines to objects, such as the eyeballs, with no sense as to how the objects interact with the surrounding space. In the test of negative space, the San Domenico Arezzo *Christ Blessing* is more modern looking, with gradations of shadows and highlights. The San Domenico Arezzo *Christ Blessing* also exhibits a strong sense of light logic, with light shown bouncing off prominent facial contours, such as the cheekbones and the brows directly above the eyebrows. The figure therefore has an impassioned gaze, rather than a vacant stare as seen in Pisa *Crucifix No 15*.

Conclusions

With a particular fine sense of light logic, the San Domenico Arezzo *Christ Blessing* is incredibly naturalistic and “modern” looking when compared to the Italo-Byzantine linear style of the Pisa *Crucifix No 15*.



Experiment 11. Figures showing a comparison of the underlying contour drawings, the use of negative spaces, and the inherent light logic of the images.

EXPERIMENT 12

13 November, 2007

Aim

To compare and contrast the facial proportions in the San Domenico Arezzo *Christ Blessing* roundel to the portrait of Christ in Pisa *Crucifix No 15*.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then built a grid scale of facial proportions, using the **Freehand Tool** with a 2 point rule in red, and based on the following parameters:
 - eyes halfway;
 - the distance between the eyes approximately one eye;
 - nose halfway between eyes and chin;
 - mouth halfway between nose and chin;
 - the corners of the mouth line up with the pupils;
 - the top of the ears line up with the eyebrows; and
 - the bottom of the ears line up with the bottom of the nose.
3. I placed the grid, individually, over the two different portraits, and then scaled and rotated the grid so that the top line of the grid (the top of the head) and the bottom line of the grid (the bottom of the chin) aligned with each portrait.

Observations

The San Domenico Arezzo *Christ Blessing* shows a far closer affinity with the facial proportion grid than Pisa *Crucifix No 15*. In the San Domenico Arezzo *Christ Blessing* the eyes are correctly placed half-way down, the appropriate distance apart. The nose is correctly placed, although the mouth is a bit too high and a bit too narrow. In the portrait of Christ from Pisa *Crucifix No 15* all the features are too high in the face, and although the distance between the eyes is accurately portrayed the mouth is much too narrow, even narrower than as depicted in the San Domenico Arezzo *Christ Blessing*.

Conclusions

The San Domenico Arezzo *Christ Blessing* is much more accurate, in terms of generalized facial proportions, than the portrait of Christ in Pisa *Crucifix No 15*.



Experiment 12. Figures showing a comparison of the facial proportions of the two images.

EXPERIMENT 13

9 November, 2007

Aim

To test for the possible presence of certain optical distortions in the San Domenico Arezzo *Christ Blessing* on the roundel, and the portrait of *St John* and to compare these results to the portrait of Christ in Pisa *Crucifix No 15*.

Equipment

CorelDRAW X3

Method

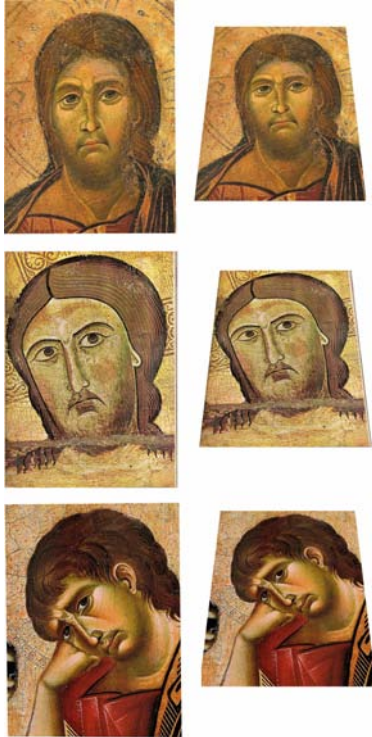
1. I placed the images onto a computer page and scaled them to the same size.
2. I then adjusted the images using the **3-D Rotate Tool**, individually tilting each one back by 25°.

Observations

This experiment shows that the San Domenico Arezzo images can be successfully manipulated using a 3-D rotation tool to alter the perspective (as one might simply by taking a real painting and inclining it away from oneself, or even standing to one side). Comparing the adjusted images with the original images, the San Domenico Arezzo portraits are enhanced by the perspective adjustment. On the other hand, adjusting the portrait of Christ from Pisa *Crucifix No 15* renders it less proportional than the original. In the San Domenico Arezzo *Christ Blessing*, for example, the eyes remain relatively centred to the face, even though the image has been tilted. However, in Pisa *Crucifix No 15*, the eyes slide even further up the face, and the top of the head spreads out like a spatula.

Conclusions

By using a 3-D rotation graphic tool the underlying opticality of an image can be more accurately determined.



Experiment 13. Figures tilted 25° using the **3-D Rotation Tool**.

EXPERIMENT 14

13 November, 2007

Aim

To compare and contrast the facial proportions of the San Domenico Arezzo *Christ Blessing* and the portrait of Christ from Pisa *Crucifix No 15* once they have been adjusted by **3-D Rotation Tool** as described in Experiment 13

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then placed the grid scale of facial proportions as created in Experiment 12 onto the two perspectively adjusted portraits.

Observations

This experiment shows that adjusted by 25° the San Domenico Arezzo *Christ Blessing* exhibits even truer realistic proportioning than the original artwork. On the other hand, the portrait of Christ from Pisa *Crucifix No 15* becomes even more disproportionate when the same **3-D Rotation Tool** is applied.

Conclusions

From this experiment it can be concluded that Cimabue very likely had the receiving support for the optical projection at an inclined angle to the hole, in which case he copied the exact optical distortion caused by this phenomenon.



Experiment 14. The facial proportion grid overlaid onto images titled 25° on the vertical.

EXPERIMENT 15

9 November, 2007

Aim

To compare the portraits of *St John* and *St Mary* on the San Domenico Arezzo *Crucifix* to establish whether parts, or all, of the elements could have been traced.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then traced around the eyebrows, the eyes, the nose and the mouth of *St John* using the **Freehand Tool**, the **Line** set to a 2 point width, colour red.
3. I then locked the objects together using the **Group Tool**, and flipped a copy of the tracing horizontally using the **Mirror Tool**.
4. To fit the tracing to the portrait of *St Mary* it was rotated 10° to the left, the traced portion of the left eye moved slightly down (green lines) and the mouth rotated an extra 7° to the left (orange lines).

Observations

This experiment shows that the portrait of *St Mary* was a tracing of the portrait of *St John*, with some shifting of the tracing paper during execution.

Conclusions

From this experiment it can be concluded that Cimabue sometimes recycled his inventions, particularly those of women.



Experiment 15. The figure of *St Mary* from the San Domenico Arezzo *Crucifix* is composed of traced elements from *St John*, shown in red, green and orange.

EXPERIMENT 16

14 November, 2007

Aim

To compare the portraits of *St John* and *St Mary* on the San Domenico Arezzo *Crucifix* to the portraits of *St John* and *St Mary* on the Santa Croce *Crucifix* in order to establish whether parts, or all, of the elements could have been traced.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to their respective sizes.
2. I then traced around the eyebrows, the eyes, the nose and the mouth of *St John* and *St Mary* on the San Domenico Arezzo *Crucifix* using the **Freehand Tool**, the **Line** set to a 2 point width, colour red.
3. I then locked the objects together using the **Group Tool**, and enlarged the tracings by 180% to the same scale as the Santa Croce figures.
4. To fit the tracing to the portrait of *St John* the ear was shifted slightly to the right (green).

Observations

This experiment shows that the portraits of *St John* and *St Mary* from the San Domenico Arezzo *Crucifix* were enlarged and traced to form the basis of the portraits of *St John* and *St Mary* in the Santa Croce *Crucifix*, with some shifting of the tracing paper during execution.

Conclusions

From this experiment it can be concluded that Cimabue sometimes recycled his inventions, particularly those of women.



Experiment 16. The figures of *St John* and *St Mary* from the San Domenico Arezzo *Crucifix* were enlarged and traced to form the basis of the composition for the figures of *St John* and *St Mary* in the Santa Croce *Crucifix*.

EXPERIMENT 17

22 November, 2007

Aim

To compare the figure of Christ crucified on the San Domenico Arezzo *Crucifix* to the figure of Christ crucified on the Santa Croce *Crucifix* in order to establish whether parts, or all, of the elements could have been traced.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same respective sizes.
2. I then used the **Interactive Transparency Tool** set at a uniform transparency of 18% to make the image of the Santa Croce *Crucifix* slightly transparent.
3. I placed this over the image of the San Domenico Arezzo *Crucifix* and found that from the feet to the armpits the torsos presented an almost complete match, with the Santa Croce image rotated approximately 3° left.

Observations

This experiment shows that the figure of Christ crucified on the San Domenico Arezzo *Crucifix* was traced and enlarged to form the basis of the figure of Christ crucified on the Santa Croce *Crucifix*. The artist, however, made some changes to the basic figure of Christ on the Santa Croce *Crucifix*. He enlarged the patellae, making them more realistic. He exposed the hips, covering them only with a diaphanous loincloth. He painted over the protrusion of the belly and the

right hip with the background cloth, having the effect of narrowing the waist and trimming the gut. He added more striations to the breastbone. He sunk the head more deeply into the chest, and straightened the arms. He also used a more naturalistic form of modeling, moving away from the somewhat more abstract and formalized outlining of the Italo-Byzantine style evident on the San Domenico Arezzo *Crucifix*.

Conclusions

Cimabue used tracings, either freshly observed from a trip to Arezzo, or some already stored from the creation of this crucifix, to create the Santa Croce *Crucifix*. He did not create the Santa Croce *Crucifix* as a fresh and original work, showing that artists of late medieval Italy were willing to recycle inventions that were traced. However, it does appear as if he re-projected a new image of the arms, as these are depicted more outstretched, with realistically executed hands in comparison to the more stylized representation of hands in the San Domenico Arezzo *Crucifix*.



Experiment 17. The figure of Christ from the Santa Croce *Crucifix* set to a transparency of 18% and laid over the figure of Christ from the San Domenico Arezzo *Crucifix*.

EXPERIMENT 18

10 October, 2008

Aim

To compare the presentation of the Christ figure in the San Domenico Arezzo *Crucifix* with the Christ figure in the Santa Croce *Crucifix* and the Christ figure in the San Domenico Bologna *Crucifix*.

Equipment

CoreDRAW X3

Method

1. I scaled images of the San Domenico Arezzo *Crucifix* and the San Domenico Bologna *Crucifix* to their correct dimension

2. I then used the **Interactive Transparency Tool** set at a uniform transparency of 40% to make the image of the San Domenico Bologna *Crucifix* transparent.
3. I placed the transparent image over the San Domenico Arezzo *Crucifix*, and compared the images.
4. I then placed the transparent image of the San Domenico Bologna *Crucifix* over an image of the Santa Croce *Crucifix* set to the same scale (therefore outside of its actual dimensions).

Observations

The top half of the figure of Christ from the San Domenico Bologna *Crucifix* matches, with some adjustments, for example the position of the head, the top half of the figure of Christ from the San Domenico Arezzo *Crucifix*. On the other hand, the bottom half of the figure of Christ from the San Domenico Bologna *Crucifix* fits more perfectly over the bottom half of the Santa Croce *Crucifix*.

Conclusions

I conclude from this experiment that there is a close relationship between these three crucifixes, and that the San Domenico Bologna *Crucifix* is likely a mid-point creation between the first execution of the San Domenico Arezzo *Crucifix* and the later execution of the Santa Croce *Crucifix*.



Experiment 18a. The figure of Christ from the San Domenico Bologna *Crucifix* set to a transparency of 40% and laid over the figure of Christ from the San Domenico Arezzo *Crucifix*.



Experiment 18b. The figure of Christ from the San Domenico Bologna *Crucifix* set to a transparency of 40% and laid over the figure of Christ from the Santa Croce *Crucifix*.

EXPERIMENT 19

15 October, 2008

Aim

To compare the proportions of the Christ figure in the San Domenico Arezzo *Crucifix* with the proportions of the Christ figure in the San Domenico Bologna *Crucifix*.

Equipment

CorelDRAW X3

Method

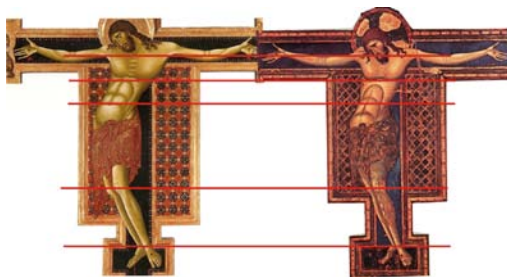
1. I scaled images of the San Domenico Arezzo *Crucifix* and the San Domenico Bologna *Crucifix* to their correct dimension
2. I placed the two figures side-by-side.
3. Using a **Two Point Rule** in red I compared the positioning of strategic parts of the anatomy.

Observations

I observed that the top half of the body has been truncated, with less length between the bellybutton and the ribs, and the breastbone and shoulders, of the San Domenico Bologna *Crucifix* compared with the San Domenico Arezzo *Crucifix*.

Conclusions

I concluded from this experiment that the San Domenico Arezzo *Crucifix*, which is more in proportion to the set proportions of an anatomical male model (exp 8) is more likely to be the original design, with the San Domenico Bologna *Crucifix* a derivative.



Experiment 19. The proportions of the figure of Christ from the San Domenico Arezzo *Crucifix* compared with the proportions of the figure of Christ from the San Domenico Bologna *Crucifix*.

EXPERIMENT 20

14 November, 2007

Aim

To compare and contrast the underlying contour drawings, the use of negative spaces, and the inherent light logic in the depictions of St Francis from the panel in the Museo di Santa Maria degli Angeli in Assisi, the Berlinghieri panel in Pescia, and the so-called Bardi Master in the Uffizi.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then tested the underlying contour drawings, the use of negative spaces, and the inherent light logic by running the images through the same diagnostics as Experiments 4, 5 and 7.

Observations

The tests show that in all instances the Assisi St Francis exhibits superior drawing skills. In testing the underlying contour skills, the artist of the Assisi St Francis uses a more subtle line than the other two artists, where the line is more graphic. In the test of negative space, the Assisi St Francis shows gradations of shadows and highlights, and the artwork also exhibits a competent light logic.

Conclusions

The Assisi St Francis is constructed in such a way as to portray a sense of the saint's individuality. It can be strongly hypothesized that the basic design of this fresco was done from a image projection.



Experiment 20. Figures showing a comparison of the underlying contour drawings, the use of negative spaces, and the inherent light logic of the images.

EXPERIMENT 21

14 November, 2007

Aim

To compare and contrast the facial proportions of the portrait of St Francis from the panel in the Museo di Santa Maria degli Angeli in Assisi, the portrait of St Francis from the Berlinghieri panel in Pescia, and the portrait of St Francis from the Bardi panel in the Uffizi.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to the same size.
2. I then used the grid scale of facial proportions constructed for experiment 9.
3. I placed the grid, individually, over the three different portraits, and then scaled and rotated the grid so that the top line of the grid (the top of the head) and the bottom line of the grid (the bottom of the chin) aligned with each portrait.

Observations

The Assisi St Francis shows a far closer affinity with the facial proportion grid than either the Berlinghieri panel or the Bardi panel. In The Assisi St Francis the eyes are correctly placed half-way down, the appropriate distance apart. The nose and the mouth are slightly high, and the mouth is a bit narrow. The ears are slightly high, but measure to the right size. In comparison however, in both the Berlinghieri panel and the Bardi panel the eyes are inaccurately placed far up in the head. Further, in the Berlinghieri panel, for example, the nose and mouth are very misaligned, and the chin much too long.

Conclusions

The Assisi St Francis is much more accurate, in terms of generalized facial proportions, than either the Berlinghieri panel or the Bardi panel.



Experiment 21. Figures showing a comparison of the facial proportions of the three images.

EXPERIMENT 22

19 November, 2007

Aim

To compare and contrast the proportions of the Christ child in the Rucellai *Madonna*, the Christ child in the Santa Trinita *Madonna*, and the Christ child in the Bigallo Master, *Madonna and Child Enthroned*.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page and scaled them to approximately the same size.
2. I then built grid scales of an average child's facial proportions, using the **Freehand Tool** with a 2 point rule in red (taking into account that the Bigallo Master is face-forward, while the other two examples are set at a view of three-quarters side-on). A baby's forehead is proportionately larger than an adult's. The halfway point on an adult is just below the eyes; with a baby, the middle of the eyes is about $\frac{3}{7}$ ths of the way up the face. The first $\frac{1}{7}$ th is measured roughly from the lower lip, and the next $\frac{1}{7}$ th places the nose.
3. I then placed the grids, individually, over the three different portraits, and then scaled and rotated the grid so that the top line of the grid (the top of the head) and the bottom line of the grid (the bottom of the chin) aligned with each portrait.

Observations

The Bigallo Master child portrait is clearly out of proportion to a child. The chin is far too large, and the eyes are too high in the head. The portrait lacks the large forehead noted in a child's anatomy. On the other hand, the Santa Trinita Christ child is much more in proportion to accepted standards of proportions for a child's anatomy. The eyes and nose are correctly placed, and the forehead is much larger than an adult's would be. The mouth, however, is placed slightly high up. Finally, the Rucellai *Madonna* Christ child is a faithful and delicate rendering of a child's portrait, with all features correctly placed.

Conclusions

Although children make difficult subjects for a camera obscura invention, for the reason that they will not sit very still for any length of time, the Rucellai *Madonna* Christ child nevertheless shows a faithful rendering to accepted proportions of a child's facial anatomy, and could therefore have been created using an optical projection.



Drawing showing accepted anatomical proportions of an average child's head.
(Available at: www.drawsketch.about.com)



Experiment 22. Figures showing a comparison of the facial proportions of the three images.

EXPERIMENT 23

23 November, 2007

Aim

To consider the accuracy of the facial proportions in the medallion figures of the Rucellai *Madonna*.

Equipment

CorelDRAW X3

Method

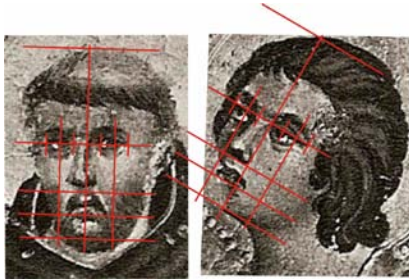
1. I placed the images onto a computer page and scaled them to the same size as the adult facial grid built for Experiment 12.
2. I placed the grid, individually, over the different portraits.

Observations

The medallion portraits of the Rucellai *Madonna* show a close affinity with realistic proportions as described by human facial anatomy.

Conclusions

The medallion portraits of the Rucellai *Madonna* could easily have been achieved using a convex lens image projection as they show a close affinity to the realistic proportions identified in human facial anatomy.



Experiment 23. Figures showing a comparison of the facial proportions of the medallion images.

EXPERIMENT 24

25 November, 2007

Aim

To test whether the facial proportions of the Christ child in the Ognissanti *Madonna* are in proportion with accepted facial proportions of an average child.

Equipment

CorelDRAW X3

Method

I placed the image onto a computer page together with the grid of a child's facial proportions (face-on) constructed for Experiment 20.

Observations

The child portrait of the Ognissanti *Madonna* is clearly out of proportion to accepted facial proportions of a real child. The chin is too large, and the eyes are too high in the head. The portrait lacks the large forehead noted in a child's anatomy.

Conclusions

It is unlikely that the child of the Ognissanti *Madonna* was created using an optical projection of a real child, as it lacks the accurate standard facial proportions of a real child. As a consequence Giotto's portrait of a child looks more like a mini-adult, scaled down to fit onto the Madonna's lap, in a similar way to other Italo-Byzantine portraits from that time period.



Experiment 24. Figure showing the facial proportions of the Christ child from the Ognissanti *Madonna*.

EXPERIMENT 25

26 November, 2007

Aim

To compare and contrast the overall drawing skills as seen in the Santa Trinità *Madonna*, the Rucellai *Madonna* and the Ognissanti *Madonna*.

Equipment

CorelDRAW X3

Method

1. I scaled the figures to the same relative sizes using the heads as guides.
2. I used the **Art Strokes, Sketch Pad Tool** to convert the bitmaps to outline sketches (exp 6).
3. I transformed the images into an appearance of photographic negatives by inverting the colours using the **Transformation Tool, Invert** procedure (exp 7).
4. I compared the relative proportions of the child figures by drawing a 2 point rule (red) through the main features, that is, the head, the chest, the left hand and the right foot.
5. I converted images of Pisa *Crucifix No 20* and the San Domenico Arezzo *Crucifix* to Greyscale (8bit) using the **Convert to Bitmap Tool**.
2. I then adjusted the contrast between light and dark to 100%, using the **Brightness/Contrast/Intensity Tool**.

Observations

The artistic observation of outline is most advanced in the Rucellai *Madonna*, although areas of the Ognissanti *Madonna* show an attention to outline, such as, the hem of the skirt and the detail of the raised right hand. The use of negative space is most subtly displayed in the Santa Trinità *Madonna*. The Ognissanti *Madonna* shows an almost sculptural solidity, an isolation rather than an integration in background and foreground detail. The overall proportions of the three images are relatively similar. However, in the Ognissanti *Madonna* it becomes clear that, although the head is relatively well described to the body, the facial features are too big, that is, they take up too much space and therefore render the portrait adult looking. Finally, the light logic in the Rucellai *Madonna* is the most advanced and perceptively defined, with areas of light grading subtly into areas of dark, perfectly rendering the soft features of a child.

On the other hand, the artist of the Ognissanti *Madonna* uses highlights flatly, and shadows serve the function of outlining shape and form.

Conclusions

The drawing Gestalt is most advanced in the Rucellai *Madonna*, which shows a finely observed and acutely accurate portrait of a small child.



Experiment 25. Images comparing and contrasting the drawing logic in the Santa Trinità *Madonna*, the Rucellai *Madonna* and the Ognissanti *Madonna*.

EXPERIMENT 26

27 November, 2007

Aim

To compare the main facial features of the Madonna in the Santa Trinità *Madonna*, the Ognissanti *Madonna* and the Crevole *Madonna*, using the Rucellai *Madonna* as a control.

Equipment

CorelDRAW X3

Method

1. I placed the images onto a computer page, and scaled them to the same relative sizes.
2. Using the **Freehand Tool**, with a two point line in red, I traced around the main features of the Madonna in the Rucellai *Madonna*.

- I then grouped these lines, and copied and pasted them onto the other three images in the sample.

Observations

The Rucellai *Madonna* is most closely associated with the Crevole *Madonna*. It also shows many points of comparison with the Santa Trinità *Madonna*. For example, the right eye and eyebrow are almost identical in shape and placement to the Rucellai *Madonna*. The nose is similar in style and position. However, Duccio “droops” the left eye more significantly than Cimabue, and Cimabue moves the mouth further over to the right side of the Madonna’s face. The Ognissanti *Madonna* is quite different in depiction, with the only point of comparison being the shape of the right eye.

Conclusions

From this experiment it can be stated that Giotto is independent from Cimabue and Duccio in his conception of the *Madonna*. Nevertheless, all three images show a certain abstract stylization which marks a certain indebtedness to an Italo-Byzantine style.



Experiment 26. A comparison of the main facial features of the Madonna in the Santa Trinità *Madonna*, the Ognissanti *Madonna* and the Crevole *Madonna*, using the Rucellai *Madonna* as a control.

EXPERIMENT 27

28 November, 2007

Aim

To compare and contrast the accuracy of the Madonna’s facial proportions in the Rucellai *Madonna* and the Ognissanti *Madonna*.

Equipment

CorelDRAW X3

Method

- I placed the images onto a computer page and scaled them to the same size.
- I reconstructed the grid from Experiment 12, to take into consideration the three-quarter presentation of the images.
- I resized the grid and repositioned it over the individual images.

Observations

The facial proportions of the Madonna from the Rucellai *Madonna* are relatively accurate to accepted anatomical proportions. The mouth is slightly too high. It is also very small. On the other hand, the facial proportions of the Madonna from the Ognissanti *Madonna* vary quite substantially from accepted anatomical proportions. The eyes and nose are placed too high, and the forehead is too small. The mouth is also placed too high, and is much too small.

Conclusions

The Madonna's portrait from the Rucellai *Madonna* could, at a point, have been invented from an optical projection, as it shows certain accurate anatomical features. On the other hand, the Ognissanti *Madonna* is unlikely, at any stage, to have been based on an optical invention, as it deviates quite markedly from accepted anatomical proportions.



Experiment 27. A comparison of the main facial proportions of the Madonnas in the Ognissanti *Madonna* and the Rucellai *Madonna*.

EXPERIMENT 28

28 November, 2007

Aim

To test “light logic” in the Santa Croce *Crucifix* (pre-flood 1996), that is, the enhancement and manipulation of light and dark by the artist, and to compare this to the “light logic” in the Santa Maria Novella *Crucifix*.

Equipment

CorelDRAW X3

Method

1. I converted images to Greyscale (8bit) using the **Convert to Bitmap Tool**.
2. I then adjusted the contrast between light and dark to 100%, using the **Brightness/Contrast/Intensity Tool**.

Observations

1. The areas of light and dark are more highly contrasted in the Santa Croce *Crucifix* than in the Santa Maria Novella *Crucifix*.

2. The artist of the Santa Maria Novella *Crucifix* has explored the gradations of light to dark in a more succinct way than in the Santa Croce *Crucifix*.
3. Generally, both crucifixes show an intelligent application of light logic.

Conclusions

The differences in light logic between the Santa Maria Novella *Crucifix* and the Santa Croce *Crucifix* are subtle, with the Santa Croce *Crucifix* showing more startling contrasts between light and dark.



Experiment 28. Figures manipulated to enhance "light logic."

EXPERIMENT 29

28 November, 2007

Aim

To compare the association between the figures of Christ crucified on the *Boston Triptych*, the crucifixion scene from Duccio's *Maestà* and the Santa Maria Novella *Crucifix*.

Equipment

CorelDRAW X3

Method

1. I scaled the scanned images of the crucifixion on the *Boston Triptych* and the crucifixion scene from the *Maestà* to their actual relative real sizes.
2. Using the **Interactive Transparency Tool** I set the scanned image of the *Boston Triptych* to a 50% transparency.
3. I then placed this transparency over the scanned image of the crucifixion scene from the *Maestà*.
4. I compared the results.
5. I then rotated the image of the *Boston Triptych* 10° on the vertical, using the **3-D Rotate Tool**.
6. I placed a 50% transparency of this image onto the *Maestà* image, and compared the results.

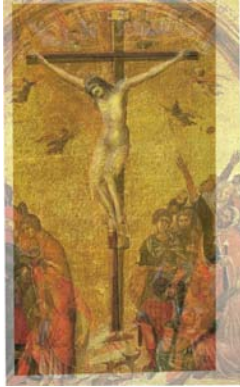
7. I then scaled an image of the Santa Maria Novella *Crucifix* to the same computer image size as the *Boston Triptych*.
8. I placed a 50% transparency of the *Boston Triptych* on top of the Santa Maria Novella *Crucifix*, and compared the results.

Observations

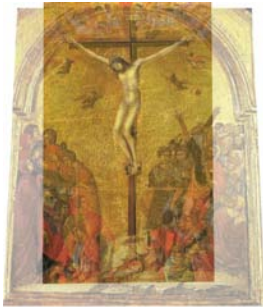
1. The figure of Christ from the *Boston Triptych* is significantly elongated in comparison to the crucifixion scene from the *Maestà*, so that the feet of the *Maestà* figure are placed relatively higher
2. Nevertheless, the arms fit, and the basic shape and hang of the body is equal.
3. However, rotating the image back 10° affords an almost perfect fit between the figure of Christ in the *Boston Triptych* and the figure of Christ crucified from the *Maestà*.
4. The crowd scene is still, nevertheless, very much closer to the crucified figure in the *Boston Triptych*.
5. Finally, although the placement and sway of the body is imitated in the Santa Maria Novella *Crucifix*, the many differences between the two poses suggest that the Santa Maria Novella *Crucifix* was observed from a different model, and is, therefore, a new invention.
6. It can be observed that the arms are placed much higher in the *Boston Triptych*, and the butt juts out more to the model's left in the Santa Maria Novella *Crucifix*, having the effect of bringing the knees more tightly in line with the vertical.

Conclusions

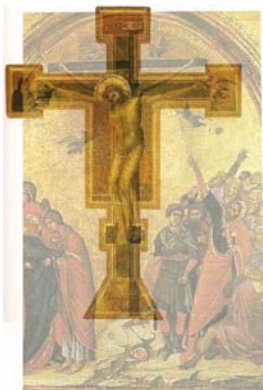
The idea of using a rotating perspective tool to realign the figure of Christ from the *Boston Triptych* with the figure of Christ from the *Maestà* is born of research which shows that artists many times, and probably inadvertently, stretched out the real image by placing the receiving support at an incline angle to the hole (see my own real life experiment with a pineapple, which I have adjusted in exp30). Therefore, observing that the figure of Christ on the *Boston Triptych* is elongated in respect to the figure of Christ on the *Maestà*, it could be concluded that the reason for this was an optical distortion. That this distortion can be fixed using computer technology is clear evidence of a primary optical invention, and suggests that the artist seems to have used the camera obscura like an ancient photocopier, in other words, he placed an existing artwork in the light and projected the image onto a support in the camera obscura, the effect being to readjust the original distortion (fig 13). That the artist was able to alter the elongation using any other mechanical means (either by design or by accident) is extremely unlikely.



Experiment 29a. A transparency overlay shows that, although very closely associated, the figure of Christ from the *Boston Triptych* is elongated in respect to the figure of Christ from the *Crucifixion* in the *Maestà*.



Experiment 29b. By first rotating the image of the *Boston Triptych* by 10° a transparency overlay of the figure of Christ from the *Boston Triptych* fits very closely with the figure of Christ from the *Crucifixion* in the *Maestà*.



Experiment 29c. A transparency overlay shows that, although closely associated, the figure of Christ from the *Boston Triptych* shows certain differences, relating to pose, to the figure of Christ from the Santa Maria Novella *Crucifix*.

EXPERIMENT 30

29 November, 2007

Aim

To test for the possible presence of certain optical distortions in my own artwork, *Lens Pineapple*, which was created using a convex lens projection.

Equipment

CorelDRAW X3

Method

1. I placed a scanned image onto a computer page, and made an exact copy.
2. I then adjusted the copy using the **3-D Rotate Tool**, tilting it back by 25° and shifting it horizontally by -22° .

Observations

The corrected image gives the impression of relatively more abundant foliage, and seems more in keeping with the proportions and shape of the photographed pineapple.

Conclusions

When I created this artwork I had absolutely no idea, just looking at the upside down image, that I was copying a distortion. I did indeed, in my naivety, have the receiving canvas support resting on an ordinary artist's easel at a slight incline to the hole, as well as having it off to the perpendicular. I do also remember that I had difficulty keeping the pineapple absolutely vertical, and it was, eventually, resting at a slight angle tilted away from the hole.



Experiment 30. Artwork tilted (middle) $25^\circ/-22^\circ$ using the **3-D Rotation Tool**.

EXPERIMENT 31

29 November, 2007

Aim

To show the proportions of the Christ figure in the Santa Maria Novella *Crucifix*, and to compare these to the proportions of the Christ figure in the crucifixion scene from the Padua cycle frescoes.

Equipment

CorelDRAW X3

Method

1. I scaled the images to relatively the same size.
2. I then placed the scale measurements from the modern anatomical diagram of a man (exp 8), as a control, onto both images.

Observations

1. Taking into account the difficulties of estimating the correct proportions due to the contraposta posing of the bodies, it can nevertheless be stated that the figure from the Santa Maria Novella *Crucifix* is more accurately in proportion to accepted modern principles
2. On the other hand, although finely crafted with attention to detail and anatomical features, the figure in the crucifixion scene from the Padua fresco cycle is, nevertheless, quite badly out of proportion around the chest area. The chest cavity is too long in comparison to the rest of the body.

Conclusions

From this experiment it can be concluded that the artist of the Santa Maria Novella *Crucifix* had a firmer control of anatomical proportion, and might well have used a light projection for the original invention.



Experiment 31. Graded markings showing proportions of the Christ figure from the Padua fresco cycle compared to the proportions of the Santa Maria Novella *Crucifix*.

EXPERIMENT 32

2 December, 2007

Aim

To show the anatomical proportions in the *Maestà*, against the controls of standard accepted modern anatomical proportions.

Equipment

CorelDRAW X3

Method

1. As a control measure, I first created a scale to the measurements of a modern anatomical diagram of a man.
2. This generally accepted scale is around 7½ to 8 heads per body length.
3. I then placed this scale accordingly over the two figures from the *Annunciation*.

Observations

1. The proportions of the angel on the *Annunciation* can be considered accurate, as compared to the standard accepted anatomical proportions of today. He measures around 8 heads to the body.
2. Proportionately speaking, Mary is slightly larger than the angel in the *Annunciation*, although still in proportion to herself. It could be conjectured that the two models were posed simultaneously, and that Mary was slightly closer to the lens.

Conclusions

I concluded from this experiment that the artist presented these figures in proportion to modern accepted anatomical measurements.



Experiment 32. Graded markings showing proportions of the two figures of the *Annunciation*.

EXPERIMENT 33*3 December, 2007***Aim**

To show the perspective of the ceiling in the *Annunciation of the Death of the Virgin* from the *Maestà*.

Equipment*CorelDRAW X3***Method**

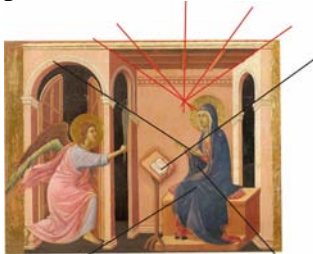
1. Using a 2 point rule in red, I traced the lines from the relevant sections of the ceiling to see if they met at a single point.
2. I then used a number of 2 point rules in black to trace other elements of the architecture.

Observations

The lines from the relevant sections of the ceiling do, indeed, meet at a single point. However, the black rules show that the artist neglected to discover a single vanishing point in other elements of the architecture.

Conclusions

From this experiment it can be concluded that the artist either understood the concept of a single vanishing point or, more likely, stumbled on this phenomenon inadvertently and failed to notice it.



Experiment 33. Red rules showing how the angle of the ceiling creates a single vanishing point. On the other hand, the black rules show how Duccio has not discovered a single vanishing point with other elements of the architecture.

EXPERIMENT 34*8 December, 2007***Aim**

To show the perspective of the ceiling in the *Washing of the Feet* from the *Maestà*.

Equipment*CorelDRAW X3*

Method

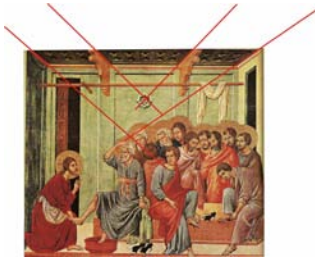
Using a 2 point rule in red, I traced the lines from the relevant sections of the ceiling to see if they met at a single point.

Observations

The lines from the relevant sections of the ceiling do not meet a single point.

Conclusions

From this experiment it can be concluded that the artist did not understand the concept of a single vanishing point.



Experiment 34. Rules showing how the angle of the ceiling does not describe a single vanishing point.

EXPERIMENT 35

8 December, 2007

Aim

To show the correlation between the architectural settings in the *Annunciation of the Death of the Virgin* and the *Arrival of St John the Evangelist*, from the *Maestà*.

Equipment

CorelDRAW X3

Method

1. I placed the images on a new page, and scaled them to their correct actual painted sizes.
2. Using the **Interactive Transparency Tool** I converted the image of the *Annunciation of the Death of the Virgin* to a **Transparency** of 50%.
3. I placed this image directly over the image of the *Arrival of St John the Evangelist*, and compared the correlation between the two images (a).
4. I then copied this pair of images to a new page.
5. I then reduced the *Annunciation of the Death of the Virgin* by 87%.
6. I attempted to position the transparent reduced image of the *Annunciation of the Death of the Virgin* over the solid image of the *Arrival of St John the Evangelist*.
7. The fit was approximately exact, except that the image of the *Arrival of St John the Evangelist* remained “longer” on the vertical, and wider incrementally to the left of the image (b).

8. I converted the *Arrival of St John the Evangelist* to a **Transparency** of 50%, leaving the *Annunciation of the Death of the Virgin* as a solid image.
9. Using the **3-D Rotational Tool** I rotated the image of the *Annunciation of the Death of the Virgin* 10° to the right on the horizontal.
10. I placed the transparent image of the *Arrival of St John the Evangelist* on top of the rotated image (c).

Observations

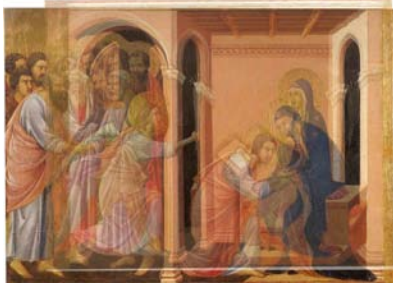
The architectural setting in the *Annunciation of the Death of the Virgin* is larger in scale than the *Arrival of St John the Evangelist*. However, although an approximate reduction of 87%, the architectural setting in the *Arrival of St John the Evangelist* varies from the architectural setting of the *Annunciation of the Death of the Virgin* on two significant points: it is longer on the vertical, and wider incrementally to the left. I realized that it was very likely that this image, that is, the architectural setting from the *Arrival of St John the Evangelist* was “copied” using an optical system, wherein the original image, that is the architectural setting from the *Annunciation of the Death of the Virgin*, became rotated on the third-dimension. This likely happened when the artist placed the original artwork on an easel outside in the direct sunlight, and copied this onto a receiving support inside a dark room using a lens. Either the original artwork, or the receiving support, or both, were rotated against the perpendicular. Testing this hypothesis by rotating the image of the *Annunciation of the Death of the Virgin* on the horizontal by 10°, I was able to make an almost exact fit of the two images, including the anomaly of the elongation and incremental widening.

Conclusions

The artist very likely used some form of optical aid to copy the architectural setting of the *Annunciation of the Death of the Virgin* to create the architectural setting for the *Arrival of St John the Evangelist*. This can be very strongly supported by the fact that the architectural setting of the *Arrival of St John the Evangelist* is not only a reduction of the architectural setting of the *Annunciation of the Death of the Virgin*, but also a slight elongation on both the horizontal and vertical planes.



Experiment 35a. A 50% transparency of the *Annunciation of the Death of the Virgin* placed over a solid image of the *Arrival of St John the Evangelist*. The architectural setting in the *Annunciation of the Death of the Virgin* is larger in scale than the architectural setting of the *Arrival of St John the Evangelist*, but the figures remain in the same scale.



Experiment 35b. A 50% transparency of the *Annunciation of the Death of the Virgin*, reduced by 87%, and placed over a solid image of the *Arrival of St John the Evangelist* shows reduction of the architectural setting, but not an exact fit, as for example to the left where there is a widening and lengthening of the image in the *Arrival of St John the Evangelist*.



Experiment 35c. To the left is the original *Annunciation of the Death of the Virgin*. The image to the right has been rotated 3-dimensionally on the horizontal 10° to the left. This causes everything to the (viewer's) right to be reduced, and everything to the (viewer's) left to be magnified, with an incremental adjustment in between.



Experiment 35d. A 50% transparency of the *Arrival of St John the Evangelist* placed over a rotation of the solid image of the *Annunciation of the Death of the Virgin*, which has been rotated 3-dimensionally on the horizontal 10° to the left. The architectural setting in the *Arrival of St John the Evangelist* now fits over the adjusted architectural setting in the *Annunciation of the Death of the Virgin*, including the incremental elongation of the elements both vertically and horizontally towards the left of the picture as seen by the viewer in the original architectural setting of the *Arrival of St John the Evangelist*.

EXPERIMENT 36
11 December, 2007

Aim

To show the perspective of the ceiling in the *Arrival of St John the Evangelist* from the *Maestà*.

Equipment

CorelDRAW X3

Method

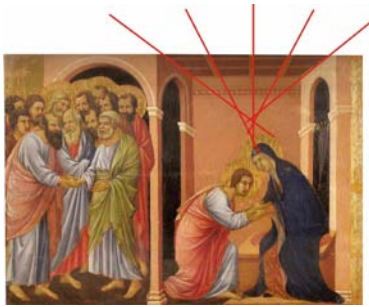
Using a 2 point rule in red, I traced the lines from the relevant sections of the ceiling to see if they meet at a single point.

Observations

The lines from the relevant sections of the ceiling meet at a single point, with the exception of the left-hand ceiling beam.

Conclusions

From this experiment it can be concluded that the artist did not measure a single vanishing point.



Experiment 36. Red rules showing how the angle of the ceiling creates a single vanishing point, except for the left-hand ceiling beam.

EXPERIMENT 37
8 December, 2007

Aim

To show the correlation between the architectural settings in the *Arrival of St John the Evangelist* and the *Gathering of the Apostles*, from the *Maestà*.

Equipment

CorelDRAW X3

Method

1. I placed the images on a new page, and scaled them to their correct actual painted sizes.

2. Using the **Interactive Transparency Tool I** converted the image of the *Arrival of St John the Evangelist* to a **Transparency** of 50%.
3. I placed this image directly over the image of the *Gathering of the Apostles*, and compared the correlation between the two images (a).
4. I then copied this pair of images to a new page.
5. Using the **3-D Rotational Tool I** rotated the transparent image of the *Arrival of St John the Evangelist* 10° to the right on the horizontal.
6. I placed the transparent image of the *Gathering of the Apostles* on top of the rotated image (b).
7. I placed scaled images of the *Annunciation of the Death of the Virgin*, the *Arrival of St John the Evangelist*, and the *Gathering of the Apostles* onto a page in a row, and used **2 Point Rules** in red to show how the scale narrows to the right and lengthens to the left (c).

Observations

The architectural setting in the *Arrival of St John the Evangelist* is larger in scale than the architectural setting in the *Gathering of the Apostles*. However, although an approximate reduction of 87% (as seen also in exp 33), the architectural setting in the *Gathering of the Apostles* varies from the architectural setting of the *Arrival of St John the Evangelist* on two significant points: it is also longer on the vertical, and wider incrementally to the left. The architectural setting from the *Gathering of the Apostles* was therefore likely “copied” using an optical system, wherein the original image, that is the architectural setting from the *Arrival of St John the Evangelist*, became rotated on the third-dimension. Testing this hypothesis by rotating the image of the *Arrival of St John the Evangelist* on the horizontal by 10°, I was able to make an almost exact fit of the two images, including the anomaly of the elongation and incremental widening. Placing the three relevant images together on the same page, it becomes evident, even to the naked eye, that the images reduce incrementally to the (viewer’s) right and magnify incrementally to the (viewer’s) left.

Conclusions

The artist very likely used some form of optical aid to copy the architectural setting of the *Annunciation of the Death of the Virgin* to create the architectural setting for the *Arrival of St John the Evangelist*, and thereafter to create the architectural setting of the *Gathering of the Apostles*.



Experiment 37a. A 50% transparency of the *Arrival of St John the Evangelist* placed over a solid image of the *Gathering of the Apostles*. The architectural setting in the

Arrival of St John the Evangelist is larger in scale than the architectural setting of the *Gathering of the Apostles*.



Experiment 37b. A rotation of a 50% transparency of the *Arrival of St John the Evangelist* placed over a solid image of the *Gathering of the Apostles*.



Experiment 37c. Placing the three relevant images, that is, the *Annunciation of the Death of the Virgin*, the *Arrival of St John the Evangelist*, and the *Gathering of the Apostles*, in a vertical row, the reduction/magnification anomaly is quite visible and comparable even to the naked eye.

EXPERIMENT 38

11 December, 2007

Aim

To show the perspective of the octagonal building in the *Temptation of Christ on the Temple* from the *Maestà*.

Equipment

CorelDRAW X3

Method

1. Using a 2 point rule in red, I traced the lines from the relevant sections of the building to see if they met at the horizontal vanishing points.
2. I then used a number of 2 point rule in black to see if these vanishing points were level at eye-level.

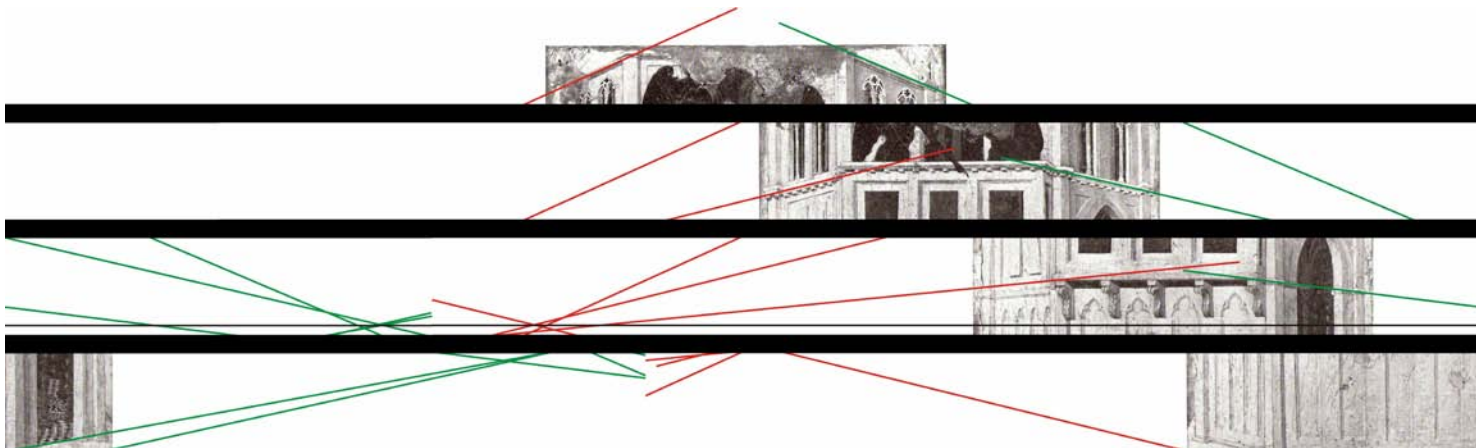
Observations

The lines from the relevant sections of the building meet almost without exception at the two lateral distance points. There is one line, that drawing the orthogonal of the architrave above the front door, which is the most inaccurate. The four points are situated exactly on the level black rule, suggesting an eye

level at about the separation of the bottom floor from the top floor, that is, more-or-less where an adult would view the building from standing height. This eye-level is the same as proposed for Brunelleschi's so-called perspective experiment of the baptistery in Florence (Tsuji 1990:279).

Conclusions

From this experiment it can be concluded that the artist either understood the concept of a vanishing points or, more likely, stumbled on this phenomenon inadvertently and failed to notice it.



Experiment 38. Red rules showing how the angles of the building lead to two lateral distance points. The black rule shows that these vanishing points are level to the eye-level of the perspective. This eye-level is the same as proposed for Brunelleschi's so-called perspective experiment of the baptistery in Florence.

EXPERIMENT 39

11 December, 2007

Aim

To show the general anatomical proportions in the *Maestà*, against the controls of standard accepted modern anatomical proportions.

Equipment

CorelDRAW X3

Method

1. As a control measure, I used the scale measurements of a modern anatomical diagram of a man from experiment 30.
2. This generally accepted scale is around $7\frac{1}{2}$ to 8 heads per body length.
3. I then placed this scale accordingly over a number of random samples from the *Maestà* to test for validity.

Observations

Taking into consideration that some figures slump forward or stand swayed to one side, while the angel in the *Annunciation* is depicted standing upright, the proportions are relatively realistic, if somewhat shorter. However, these proportions are mostly standard to each other in single works, as well as across the whole of the *Maestà*, that being around 7 to 7½ heads per body.

Conclusion

I concluded from this experiment that, even across a range of scales, the artist has kept his figures in proportion to each other, and that these proportions are relative to modern accepted anatomical measurements. However, I also concluded that adjusting the figures on the third dimension (in other words, accepting that the artist had the support at an inclined plane to the hole or lens) would probably “correct” any slight discrepancies (see exp 40).



Experiment 39a. Graded markings showing proportions of figures from *Christ Before Herod*.



Experiment 39b and 39c. Graded markings showing proportions of figures from *The Arrival of St John the Evangelist*, and the front panel of the *Maestà*.

EXPERIMENT 40

15 November, 2008

Aim

To see if the full length figures in *Christ Before Herod* from Duccio's *Maestà* could have been distorted vertically by being placed on an inclined support, thereby resulting in a stretched-out optical anomaly.

Equipment

CorelDRAW X3

Method

1. As a control measure, I used the proportions, based on the length of the face, of a modern anatomical drawing of a male model (exp 8).
2. I then isolated the image of two figures from the group, which I rotated vertically -10° using the **3-D Rotational Tool**.
3. I placed the standard proportions over the first, untouched image, and the same proportions over the rotated image.

Observations

Rotating the image on the third dimension results in a more "realistic" appearance for both figures, where the heads are now more in scale with the bodies.

Conclusion

I concluded from this experiment that Duccio may well have lain the receiving support at an inclined plane to the hole (exp 30).



Experiment 40. Graded markings showing proportions of figures from *Christ Before Herod*, where left the image is untouched and right the image has been rotated vertically -10° .
